UNIVERSITY OF ALBERTA

A SYSTEMS EVALUATION OF POTATO HARVESTING AND DAMAGE IN THE PROVINCE OF ALBERTA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Systems Evaluation of Potato Harvesting and Damage in the Province of Alberta" submitted by Kompancory Vazhappallil Abraham in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In this study, potato damage in harvesting, damage was assessed and data collected from seven dissimilar farms using four different types of harvesters over four different varieties of crop.

The studies led to the following conclusions.

A. The relative weights of damaged potato tubers in comparison with that of undamaged were found to be 20% larger than the undamaged.

B. The severity of damage has been classified into 4 types and the percentage level of damage has been calculated by weight and by number and is reported for each farm. It would appear that over 35% of the total produce is being damaged at the time of harvest. The damage percentage varies between 24 and 66% of total crop.

C. The total damage index for all the farms has been computed to be between 47 and 209 using a weighting factor for slight versus serious damage.

D. The damage done by one foot of harvester conveyor was found to be

	Damage Index
Digging Section	0.95 to 6.67
Elevating Section	0.87 to 5.12
Delivery Section	0.65 to 2.82

E. The relationship between the forward speed of operation and damage done has been analyzed. The correlation between the coefficients were computed for speed versus damage percentage variables. From the observed data it was found that the best fit appears to be a parabolic curve. The best correlation coefficients found were .45, .51, .39, .55, .11, .33 and .18. They were obtained from seven farms using the equation $y = a + bx + cx^2$. Only 30% of the variation of damage was accounted for by the variation of speed. It was concluded that there is no definite relationship between damage done and forward speed of operation.

The benefit of the studies will be greatest to those farmers who have seen damage tests and the percentage calculations resulting from their methods of operation in their field and on their crops. In general, farmers were not aware of the damage which they do in the field until they saw the bright red colour of stained damaged potatoes.

Due to the unfortunate, delayed timing of the harvesting season in 1967 the study could not be extended for the late harvest crops.

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PART I

INTRODUCTION AND OBJECTIVES

In 1968, 25,400 acres of potatoes were grown in Alberta. The Province had 8% of the Canadian and 43.5% of the Prairie provinces' potato acreage. In 1966-67 Alberta produced 195,350 tons of potatoes worth 9,650,000 dollars. They were sold as whole potatoes, washed and packed ready to market, processed chips, or flakes and granules in all of which black spots, the end result of damage, are unacceptable. Damage studies in both the U.K. and parts of the U.S.A. have shown that as much as 50% of the crop may be damaged in the field and rejected before sale.

Sparks (52) reported that 11.5 percent of the potato tubers were injured badly enough during harvesting and storing, to be classed as having hard and serious bruises. In several tests conducted at the University of Idaho, Aberdeen Branch Experiment Station, according to Sparks (53) sound tubers did not rot even under unfavourable conditions but tubers that were badly injured rotted under the best possible storage conditions.

Sparks, McMaster, Dixon, Works and Wilson (54) reported that in a storage period of eight months serious bruises may result in rot and storage losses of 50% which includes the moisture loss from sound tubers which may be as low as 4%.

The Potato Marketing Board of U.K. in a 1967 publication stated that "33% of the crop, or one out of every three potatoes grown, is so seriously damaged on the farm that it falls below the Boards' ware standard". Only potatoes of that

standard may be sold for human consumption.

While the systems of potato harvesting in Alberta are not similar to those of Idaho and the U.K. comparisons in general principle can be made. If a similar proportion of the potato crop is damaged in Alberta about three million dollars a year is lost.

This lends considerable practical benefit to the objectives of this thesis. These are to determine the relationships between:

1. the potatoes, by weight, being damaged and the total crop weight
2. the speed of operation of the harvester and the extent of damage
3. the damage and the harvester conveyor length on a foot run basis
4. the average weight of the damaged and the undamaged potatoes
5. the damaged potatoes on weight basis and by a simple count.

Para-cresol was selected as a means of assessing damage in the field. Under normal conditions damage is not visible until the black spots occur months later in store.

The writer of this thesis is a native of Kerala, a state where potatoes are a rare crop, and a luxury food item. Thus an historical background to potato migration to Canada and the method of cultivation has a place in this thesis. It is included in the literature review.

PART II

LITERATURE REVIEW

2.1 Introduction.

Salaman (49) states that the cultivation of potatoes was first recorded around 200 A.D. in the Andes Mountains area of Peru. According to Fraser (21), Spanish and English explorers in the 16th Century recognized the excellent food value of potatoes and they became an important source of provisions for their ships. These explorers introduced potatoes to their native European countries. Hatfield (33) quotes hospital records in Seville, Spain which show purchases of potatoes as early as 1573.

2.1.1 Important Dates in Potato Cultivation

According to Fraser (21), Grubb and Gilford (30) and Hatfield (33) the following dates are important in Potato Cultivation:

1524 The Spanish were the first to find potatoes in Peru, South America.

1545 Sir John Hawkins first introduced the potato in Ireland where it was neglected until re-introduced in 1585.

1565 Sir John Hawkins brought potatoes (Solanum tuberosum) back from Virginia but they were identified as sweet potatoes (Impomoca batatoa).

1585 Sir Walter Raleigh took potato tubers from Virginia to Ireland.

1593 Gaspard Banhvn, a French farmer, first started growing potatoes in France.

1624 ——— Potato production was started in Canada at Port Royal, Nova Scotia by an Acadian settlement which received a barrel of tubers as a present from the captain of an English ship.

1630 The cultivation of potatoes was banned in France by the Parliament of Besancon on the grounds that they caused leprosy.

1665 Potatoes were being cultivated in Lorraine, France.

1728 Thomas Prentice planted the first potato crop in Scotland.

1771 Parmentier of France wrote a treatise on the merits of potatoes as a means of overcoming a period of famine.

1787 One of France's worst famines resulted, ended with the extensive cultivation of potatoes. The new crop was credited with saving the lives of thousands.

1800 The potato was accepted as a basic food in France after Parmentier presented a bouquet of potato flowers to Louis XVI thereby making the potato popular throughout Europe.

1840 Late blight disease wiped out the potato crop for a second time in Ireland, one of many such potato crop failures.

1921 Canada produced its largest potato crop, 4 million tons from 784,500 acres.

1940 Canada had a record low yield crop with an average of 3.5 tons per acre.

1966 Canada had the highest average yield per acre, 8.3 tons per acre.

2.2 POTATO CULTIVATION.

The bulk of the potato crop of the world according to Grubb and Gilford(30)and McIntosh and Watson (39) is grown in the "short season" territory. Dabbs and Nelson (13) reported in 1963, that

> "although the potato will produce a good crop of tubers under widely differing conditions of soil and climate, this crop requires certain rather definite conditions in order to produce its maximum yield".

They further stated that today potatoes are grown in every Canadian province and account for a larger farm cash value than the total of all other fruits and vegetables grown in this country. Table 1 shows potato production in Canada.

2.2.1 Soil and Climate Requirements.

The yield, shape and general attractiveness of tubers, according to Parent, Black and Callbeck (41) depends largely on the texture and physical composition of the soil. Dabbs and Nelson (13) reported that the best potatoes are produced where:

1. the growing season temperatures range from 60 to 70 degrees F
2. the soil is rich, deep, friable, well-drained medium or sandy loam, free from clods and stones, moderately acid, and adequate in organic matter.
3. the pH levels are between 5.0 and 5.4
4. cool nights.

The above mentioned requirements help to explain why Alberta produces high quality potatoes.

Table 1: Potato Production in Canada. Crop Years 1960-61 to 1968-69 (inclusive) (-000 cwts)

Province	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69 Estimate
Prince Edward Island	7,200	7,623	7,462	8,300	8,372	7,341	10,776	9,607	9,010
Nova Scotia	953	1,053	932	1,000	965	858	973	693	643
New Brunswick	8,700	10,162	10,690	10,828	11,610	11,280	14,450	12,585	9,882
Quebec	9,933	9,516	9,609	8,364	8,208	7,239	8,770	7,938	9,184
Ontario	8,935	9,819	9,581	9,762	10,494	10,584	10,003	7,344	8,438
Manitoba	1,530	767	2,622	2,205	2,940	3,100	3,062	2,900	2,700
Saskatchewan	780	357	975	1,100	920	970	619	576	500
Alberta	2,430	2,545	3,100	2,500	2,429	3,000	3,907	3,200	3,400
British Columbia	2,235	2,266	2,000	1,720	1,795	2,100	2,119	1,900	2,100
Total Canada	42,696	44,108	46,971	45,809	47,733	46,472	54,679	46,743	45,857

Source: Dominion Bureau of Statistics, Ottawa, Canada.

2.2.2 Irrigation Requirements.

According to Dubetz, Russell and Hill (15) potatoes do well and are a good cash crop under irrigation. The Alberta Department of Agriculture (3) states that careful attention to moisture supply, from the time the tubers begin to form until harvest, results in a high quality yield. The Alberta Department of Agriculture (1) indicates that potatoes need frequent light irrigation: "about every three weeks". According to a recommendation by Dubetz and Hobbs (14) the average consumptive use of water for potatoes grown in southern Alberta under good irrigation and fertility management, is 20 inches, and the average daily use is 0.15 inches.

A temporary shortage of moisture, which checks growth, reduces both yield and quality. Parent, Black and Callbeck (41) agreed that this statement is particularly true of the Netted Gem, which is the main variety grown in Alberta. It is well known to farmers that the number of clods in an irrigated potato field is less than in a non-irrigated field. The Engineering Research Service of the Canada Department of Agriculture (8) reported that the presence of clods and stones in potato field is a major concern in many regions of Canada.

2.3 COMMERCIAL POTATO PRODUCTION IN ALBERTA

2.3.1 Growing Areas

The production of commercial potatoes in Alberta is concentrated according to King (37) in the following two regions.

1. Irrigation districts in the southern part of the Province.
2. Edmonton area,within a 50 mile range of the city limits.

2.3.2 Southern Alberta.

Two-thirds of the total acreage of potatoes grown is in southern Alberta. The frost-free period is about 120 days and the annual precipitation is about 13 inches, of which approximately 9 inches falls during the growing period. Elevations of the irrigation districts range from 2600 to 2900 feet above sea level. Table 2 shows the number of growers and the acreages of potatoes grown in southern Alberta in 1967.

2.3.3 Edmonton Area.

One quarter of the total Alberta potato acreage is grown within 50 miles of Edmonton where the frost-free period is 80 to 90 days and the annual precipitation is about 17.5 inches, of which approximately 13 inches falls during the growing season. The potato farms of the Edmonton area are from 2100 to 2300 feet above sea level. There are no major irrigation schemes around Edmonton. According to King (37) in 1962 there were four growers using sprinkler irrigation systems to supplement rainfall.

Table 2: Analysis of 1967 Southern Alberta Potato Acreage.

	Location	Number of Growers	Acreage
1.	Improvement District No. 11812	4	106
2.	County of Forty Mile No. 8	9	867
3.	County of Lethbridge No. 26	28	800
4.	County of Newell No. 4	42	3376
5.	Municipal District of Taber No. 14	44	5995
6.	Perimeter Growers	22	163
	Total	149	11307

2.4 POTATO VARIETIES.

In 1967 there were fifteen varieties of potatoes grown in Alberta. The Alberta Department of Agriculture (4) and Finney, Hall, and Thompson (19) agreed that potato varieties differ in:

1. resistance to mechanical damage.
2. yield per acre.
3. time of maturity.
4. depth of growth.
5. cooking and marketing qualities.
6. resistance to various diseases and insects.
7. appearance.

According to the Alberta Department of Agriculture (2) the following varieties were grown in Alberta in 1967:

1. Netted Gem*
2. Norland*
3. Warba*
4. Pontiac
5. Early Gem
6. Bliss Triumph
7. Irish Cobbler
8. Kennebec
9. Viking
10. Norgold*
11. Chinook
12. Sable
13. Cherokee
14. Haig
15. Snowflake.

* Crop varieties included in the study.

Parent, Black and Callbeck (41) reported that significant differences exist between certain potato varieties in their response to applied stress or surface force. From the stand point of the stress required to rupture the potato skin and tissues beneath the skin, Finney, Hall and Thompson (19) claim that Kennebec is significantly lower in resistance to mechanical injury than Netted Gem.

According to Glaves and French (25) physical handling quality of a potato is dependent on its shape. Table 3 below gives some of the important potato varieties in Alberta based on acres planted and their shape.

Table 3. Important Potato Varieties and Shape of the Tuber.

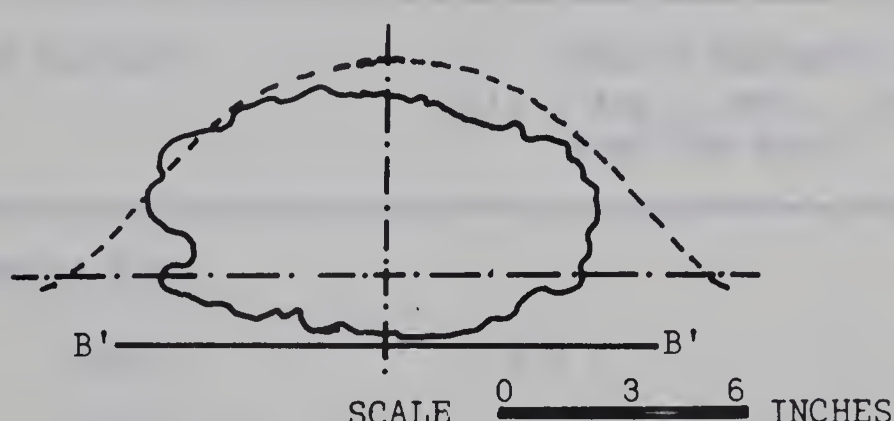
Variety	Tuber Shape
Netted Gem	long cylindrical
Warba	short, round
Norland	oblong
Kennebec	elliptical to oblong

Glaves (24) revealed that a round potato can be retained on an apron of wider pitch having greater separating capacity than a potato of any other shape having the same weight. Separating potatoes from soil, clods and stone is a function of the harvester in which considerable damage may occur.

2.4.1 <u>Habit of Growth</u>.

The habit of growth or the distribution of potatoes in a ridge differs according to the varieties. The study conducted by Bailey (6) on six Scottish potato varieties - Majestic, Arran Consul, Doon Star, Great Scot, Golden Wonder and Arran Banner found that the Majestic was the shallowest and the Arran Banner was the deepest variety. He indicated that the general form of the distribution of potatoes was elliptical. Figure 1 shows an outline drawn round all the potatoes in the experiment, excluding Arran Banner.

Figure 1. An outline drawn round five varieties of potatoes showing the habit of growth*.



*Note. This figure was adapted from Bailey (6), and the line B' - B' is referred to on Page 64 of this thesis.

The author further stated that:

> "The distribution of the potatoes in the plot is not symmetrical about the centre line of the ridge: inspection of all similar diagrams shows that this is not in general connected with the habit of growth of the potatoes, but merely arises from cumulative errors in steering the tractor, in earthing up and cultivating".

2.4.2 Crop Yields.

Finney, Hall and Thompson (19) and King (37) found that potato crop yields vary from one farm to another with:

1. time of harvest
2. variety
3. fertility of the field
4. cultivation practices
5. temperature of growing season.

Table 4 below shows average potato yields according to the time of harvest as reported by King (37).

Table 4: Potato Varieties grown and Average Yield per Acre in Alberta.

Area and Variety	Time of Harvest July - Aug.	Time of Harvest Sept. - Nov.
	tons per acre	tons per acre
Edmonton Area		
Warba	4.5	-
Netted Gem	-	6.2
Southern Alberta		
Warba	6.6	7.6
Cobbler	6.6	6.7
Norland	9.8	8.9
Pontiac	10.5	11.2
Netted Gem	5.4	9.7

2.4.3 Potato Growers' Net Returns

The findings of King (37) suggested that the net returns to the grower for his labour and management in potato production depends on many factors. Some of these are:

1. Cost of production
2. Yield per acre
3. Price received per unit weight
4. Amount of damage.

The price received by growers per unit weight of potatoes varies with:

1. Grade of the product
2. The overall supply and demand situation
3. The month during which the produce is sold

Table 5 below shows the price received per unit weight for potatoes sold in 1965 and 1966 as reported by Williams (59).

Table 5: Price of Potatoes per Ton.

Year	Price, dollars per ton
1965	57
1966	48

The price fluctuations were particularly evident when the price of the early harvest crop, often known as "new" potatoes, was compared to the price of the late harvested or "main" crop of potatoes. King (37) claimed that in Alberta, prices received by farmers for their first deliveries of "new" potatoes ranged from 80 dollars to 90 dollars per ton. However, later in the year

the main crop was sold for 20 dollars per ton.

2.4.4 Market Requirements.

According to Farm Mechanization (17) consumer surveys showed that there was an ever increasing demand for higher quality vegetables which includes the potato. In order of priority, the housewife has indicated that she considers the six following qualities to be of the greatest importance in buying potatoes.

1. Freedom from damage
2. No deep eyes
3. Cleanliness
4. Regular shape
5. The right size
6. The colour of skin.

Talburt and Smith (55) claimed that, to maintain the quality of products from the potato processing industry, an important factor is that potatoes should go into storage with the least possible injury.

2.5. POTATO HARVESTING AND DAMAGE.

2.5.1 Introduction.

Harvesting a root crop involves lifting the crop with mechanical equipment and separating it from the soil. According to Richey, Jacobson and Hall (47) the variables of soil types and conditions are added to the usual crop variables encountered in above ground harvesting crops such as wheat. Root harvesting machines are often adapted only to the area and soil types in the locality in which they were developed. Dabbs and Nelson (13) wrote that "regardless of the means used to remove the tubers from the ground - fork, plow, digger or potato harvester - care must be taken in order that injury is kept to a minimum". They added that "it is of the utmost importance in avoiding storage losses". Green (26,27,28 and 29) corroborated the above statement.

2.5.2 Potato Harvesting.

The potato harvesting season in Alberta usually starts in July and continues up to November. The crop harvested early in the season is commonly called early potatoes and that harvested late in the season is known as late potatoes or main crop potatoes. The harvesting operations are carried out in two stages. They are:

1. Haulm destruction.
2. Tuber harvesting.

The net-work diagram, Figure 12 on page 80 shows the prevailing potato harvesting systems in Alberta.

2.5.3. Early Crop Harvesting.

If the potatoes were intended for immediate sale, or for early marketing as "new" potatoes are, Dabbs and Nelson (13) suggested that they are often harvested in a very immature condition. King (37) found that the harvesting times of early potatoes were determined by the market conditions rather than the maturity of the crop. Dabbs and Nelson (13) recommended that the early market crop "...be marketed as rapidly as possible after being harvested in order that heavy losses, due to damage, may be avoided".

2.6 HAULM DESTRUCTION.

Haulm destruction has recently become an increasingly popular practice in most potato growing areas of Alberta. There are commonly three terms used for the same operation: vine killing, top killing, and haulm destruction. According to Dabbs and Nelson (13) there are several reasons for killing potato tops prematurely. They are to:

1. Increase the tuber skin resistance to mechanical injury.
2. Reduce the time and work involved in harvesting by removing the mass of living tops that would interfere with the normal operation of digging equipment.
3. Prevent late season infection by virus disease and late blight.
4. Stop growth when the tubers are the desired size.

5. Eliminate dependence on natural death of the plants or their destruction by frost, thus enabling the farmer to begin harvesting on a date independent of weather.
6. Reduce or eliminate losses through rot in storage.

Digging the crop in a field that has shown signs of late blight disease can be more costly in terms of loss in storage when any green leaves or stem persist. Spores of the disease are likely to be present on the plants and on the surface of the soil. When the crop is being harvested many tubers pick up spores and carry them on their skin into the storage quarters. As soon as these spores germinate, the tubers start to decay. To control losses caused by late blight rot, the plants are killed and digging is delayed for at least ten days after all leaves and stems have died. During this period, many spores also die.

2.6.1 Methods of Haulm Destruction.

There are two general methods for killing the potato tops prematurely. They are:

1. Mechanical
2. Chemical.

2.6.2 Top Killing (mechanical)

Machines that cut off the plants near ground level and shred them may be used to prepare a potato field for harvest. According to Glaves and French (25), these machines are called mechanical beaters or top beaters.

Top beaters usually are set to operate about one inch below the top of the potato ridge. However in this position some tubers that are near the surface may be injured, especially if the wheel tracks are rough and uneven. In addition, knocking soil from the crests of the ridge increases the danger of greening and frost damage.

It is not uncommon to set the beater to operate above the ridge top so that 1 1/2 to 2 inches of the stalk are left. Parent, Black and Callbeck (41) indicated two disadvantages of this practice:

1. With warm autumn weather, new growth may develop, particularly with late maturity varieties such as Netted Gem.
2. The stalks may carry the late blight fungus, which may infect the tuber at digging time.

2.6.3 Top Killing (chemical).

The most accepted method of removing tops is to spray them with a solution containing a chemical recommended for this purpose. Some of the recommended chemicals are:

1. Copper sulpate
2. Sodium arsenite
3. Diquat 1, 1- ethylin - 2,2, dipyridylene (Reglonè)
4. Dinitro (Synox)

The most commonly used chemical in Alberta is sodium arsenite. This is sold as a liquid concentrate and is applied,

often by aircraft, at one gallon per acre. At least 30 pounds per acre are needed to give a slow kill with copper sulphate, whose action can be improved by adding 15 pounds of common salt. Compared with sodium arsenite, copper sulphate chemical is expensive.

2.6.4 Time of Harvest

Main crop potatoes are usually harvested eight to ten days after the tops have been killed either by frost or artificial methods. If the tops are not killed by frost early in September, the usual practice among Alberta growers is the application of top killers, so timed that harvesting can be completed before severe frosts occur which will render the potatoes unfit for sale.

Potatoes to be consumed between July and November are usually sold direct from the field as harvested without storage. Potatoes for consumption in winter and spring are stored from late November to June. It is in storage that the effect of damage increases.

2.7 TUBER HARVESTING

2.7.1 Functional Requirements of the Potato Harvesting Machine.

The functional requirements of the harvesting machine according to Sides (50) and Weaver et al (56) are dictated by:

1. Physical properties of the produce
2. Rate of harvesting
3. Methods of cultivation

4. Crop maturity
5. Requirements of the processor
6. Weather
7. Soil conditions.

During either manual or mechanized harvesting of any root crop, reduction in quality or increase in a need for subsequent labour is due in part to imperfect separation of the desired product from its associated foreign material. In contrast to manual harvesting, mechanical harvesting employs mass collection, which results in the collection of material other than that desired, hence reduction in purity of the product.

2.7.2 Types of Mechanical Harvesters.

Hopkins (35) claims that the susceptibility of potatoes to mechanical damage creates many problems for both machinery designers and operators.

Mechanical potato harvesters can be divided into three types:

1. Potato spinners
2. Potato diggers
3. Potato combines.

2.7.3 Potato Spinners

A typical machine according to Harris, Muckle and Shaw (32) consists of a tool similar in shape to the front cutting edge of a plough hereafter referred to as a share. The share travels under the ridge containing the potatoes, lifting soil and potatoes onto a series of rapidly rotating tines. The tines, which are radially mounted in a hub rotating in a horizontal plane, are

driven by the tractor power-take-off. The plane of the spinner on some machines can be adjusted between the horizontal and vertical position while on others it is fixed in a near vertical position. The tines break the soil of the ridge and throw it sideways against a rope net, which allows the soil to pass through and the potatoes to fall on top of the ground.

Farm Mechanization (17) reported that 8.90 percent of the potato crop by weight, was severely damaged while harvesting with potato spinner.

2.7.4 Advantages of Potato Spinners.

The main advantages of using potato spinners are:

1. Capable of working under wet soil conditions
2. Easily manoeuvrable.

2.8 POTATO DIGGER AND POTATO COMBINE.

2.8.1 Potato Digger.

The available potato diggers are of two types, which are capable of lifting:

1. One row at a time, usually known as a single row digger
2. Two rows at a time, often called a two row digger.

Huber (36) described the potato digger as a piece of equipment that lifts the entire ridge containing the potatoes. The contents are raised by the forward motion of the lifting share and depostied on a continuous conveyor. The soil falls through the links and the potatoes pass off the end of the elevator onto the ground.

2.8.2 Potato Combine.

According to Glaves and French (25) potato combines are modified potato diggers with facilities to transfer potatoes in bulk to transport vehicles. The combination aspect includes lifting the crop, separating the potatoes from the soil and transfering to a truck. Martin and Humphery (38) stated that potato combines are generally of two types: one capable of lifting one row at a time, the other capable of lifting two rows at a time.

According to the nature of the drive provided to the potato combines, they can be either pull-type or self-propelled.

2.8.3 Functions of a Potato Harvester.

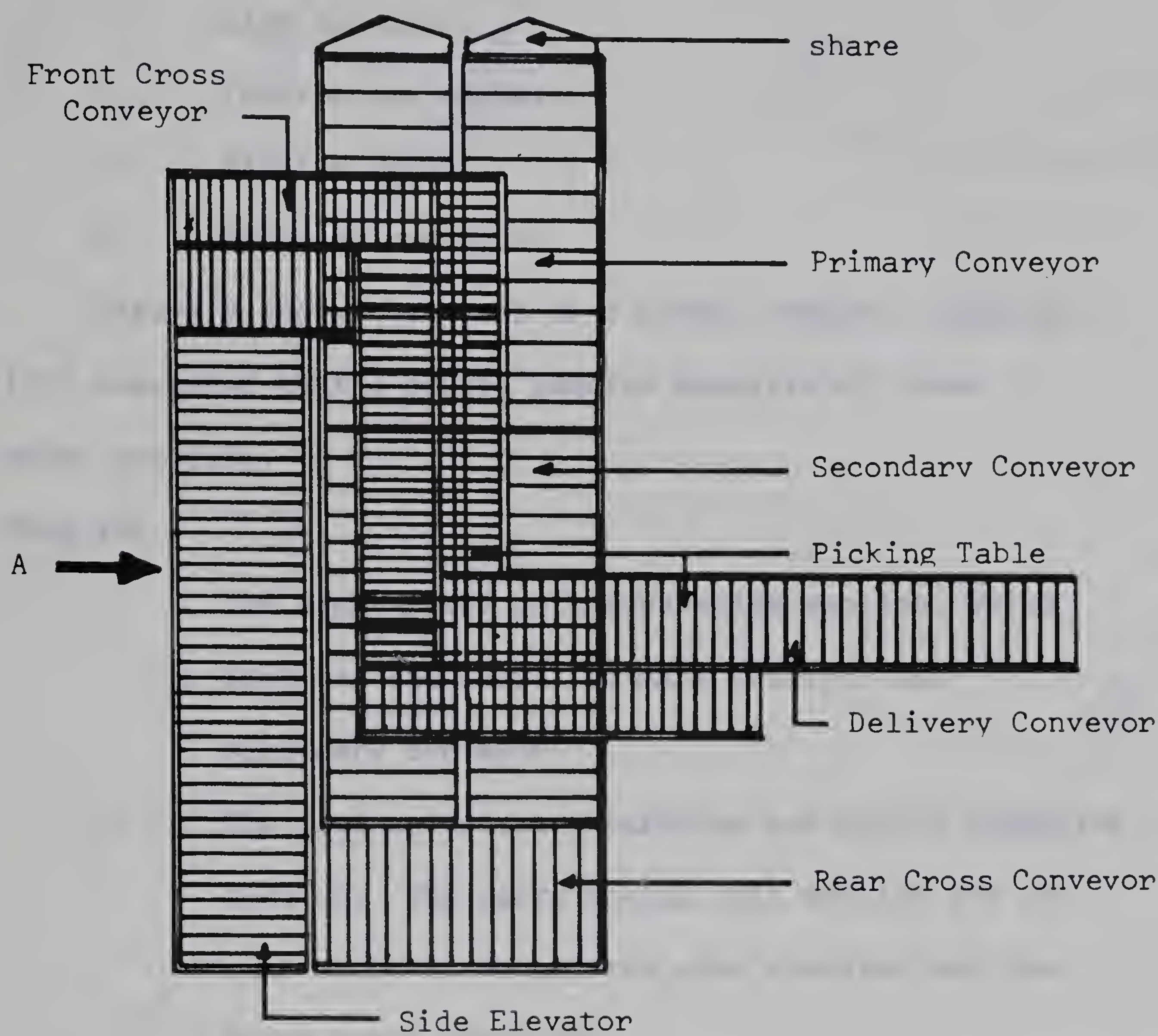
Glaves and French (25), and Hawkins (34) reported that a potato harvester must perform several functions under a wide variety of field conditions and with different varieties, shapes and sizes of potatoes. These functions are:

1. Excavation of the potato ridge
2. Elevation and separation of loose soil
3. Separation of clods and stones
4. Separation of haulm and roots from the potato
5. Inspection and sorting on a picking table
6. Transfer to a bulk transport vehicle.

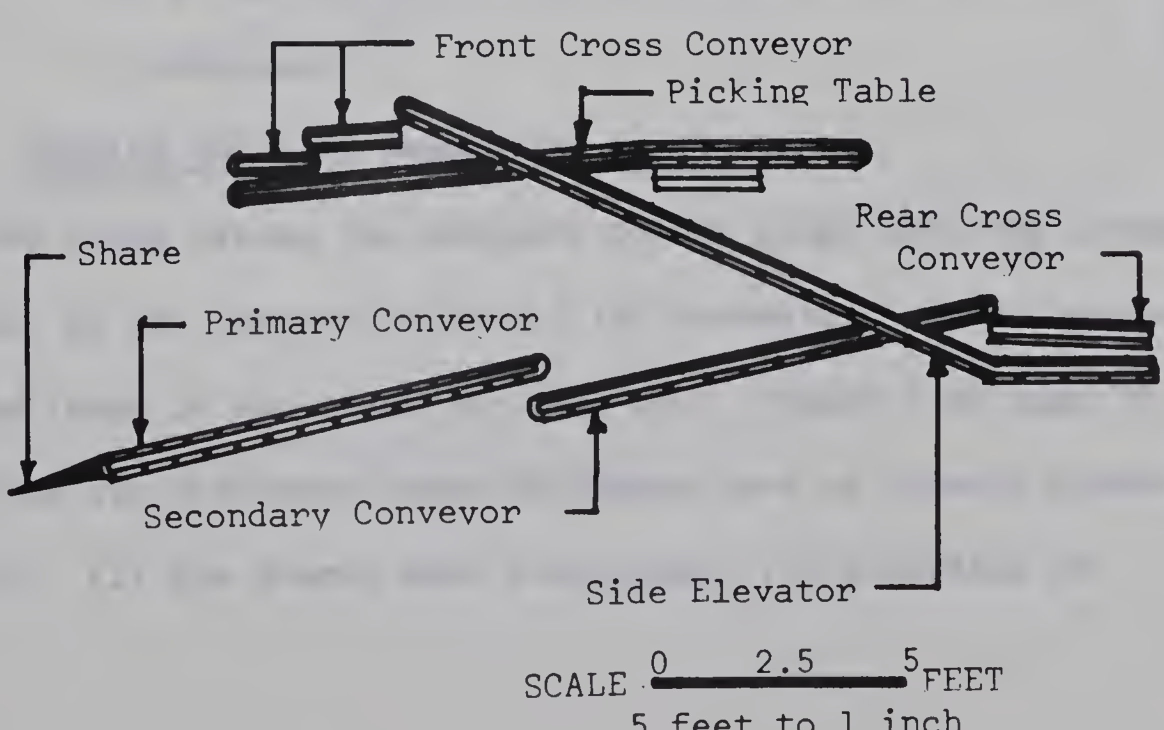
Irrespective of the classification, a potato combine consists of:

1. A share
2. Primary conveyor
3. Secondary conveyor

Figure 2. Plan and Side View Showing the Main Parts of a Combine.



Side view of a potato combine in the direction of arrow A in above plan view.



4. Rear cross conveyor
5. Side elevator
6. Front cross conveyor
7. Picking table
8. Delivery conveyor.

Figure 2 shows the parts of a potato combine. Hawkins (34) suggested that a potato combine consists of three major sections.

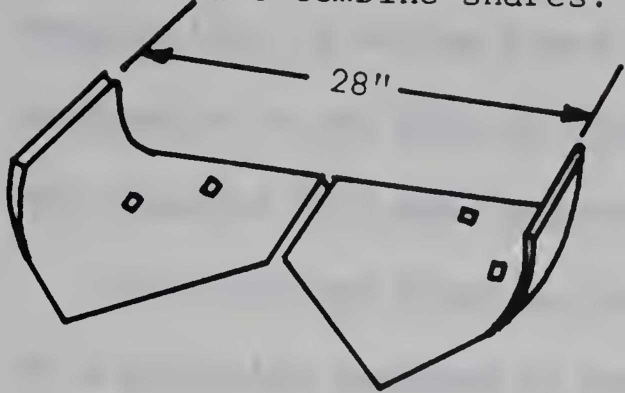
They are:

1. The digging and soil separating section, which includes the share, primary conveyor and secondary conveyor.
2. The clod and stone separating and potato elevating section. The parts making this section are the rear cross conveyor, the side elevator and the front cross conveyor.
3. Inspection table and delivery section, which include the flat bed inspection conveyor and delivery conveyors.

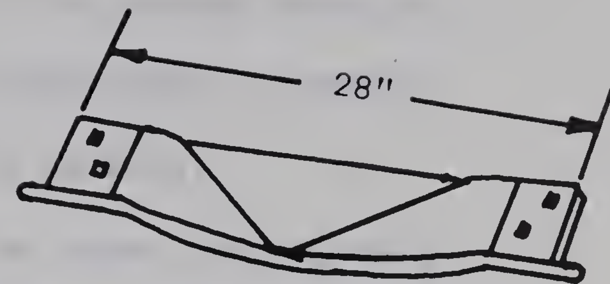
2.8.4 <u>Digging and Soil Separating Section</u>.

The share raises the complete potato ridge onto the primary conveyor by the forward motion of the harvester. On a two-row machine there is one share for each row. Figure 3 on page 26 shows the six different types of shares used by Alberta growers in 1967. All the shares were stationary, yet according to

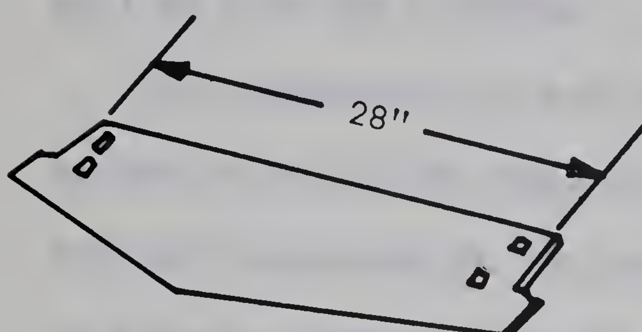
Figure 3. Potato combine shares.



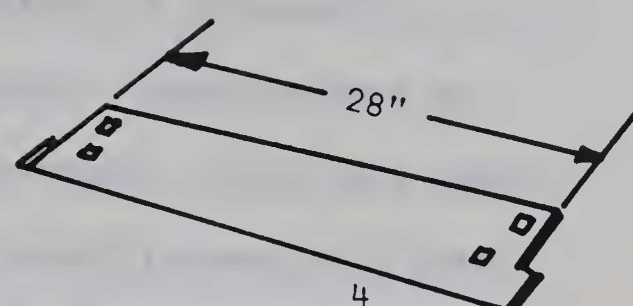
1
Farm No. 1
1964 Dahlman Combine



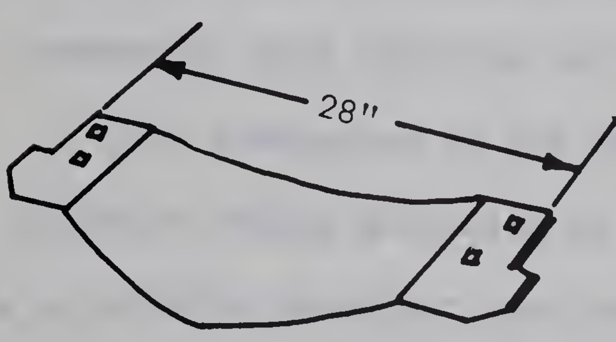
2
Farm No. 2
1967 Lockwood Combine



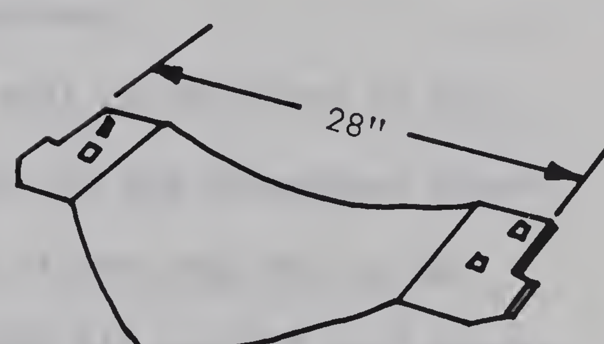
3
Farm No. 3
1964 Dahlman Combine



4
Farm No. 5
1961 Farmhand



5
Farm No. 6
1964 Dahlman Combine



6
Farm No. 7
1967 Dahlman Combine

Note: 1,3,4,5, and 6 recommended for sandy soil
2 recommended for cloddy conditions.

Hawkins (34) "a moving share such as a disc plough disc is preferable to any form of stationary blade share". Hamblin and Chalmers (31) are in agreement with Hawkins.

The soil and potatoes raised by the share are conveyed to a mechanism designed to separate the contents of the ridge. This section, say French (22) and Hopkins (35), is made up of endless rod link elevators which agitate the potatoes and soil as they are conveyed.

The separation of soil and potatoes is obtained by agitation and by the angle of elevation. Large volumes of soil are separated at the primary conveyor. It is well known to Albertan farmers that the separating efficiency of a potato harvester is greatly reduced when the soil is either too dry or too wet. In the former case the problem is essentially one of separating the potatoes from soil clods, in the latter case separation from adhering soil is involved.

The dimensions of the share as well as the width of the conveyor varies according to the width of the harvester; which is a variable dependent upon the width of the crop row to be harvested. However the farmers studied all used 28 inch shares. The conveyor has different width, 28 to 32 inches, depending on the manufacturer. The cross section of most links of the conveyor are circular and has 5/16 - 5/8 inch in diameter.

2.8.5 <u>Clod and Stone Separating Section</u>.

The mechanical separation in a potato combine, according to Glaves (24) is accomplished by a sifting action through rod

link conveyors. Glaves and French (25) indicated other methods of achieving this sifting action; by the use of:

1. rotating drums
2. oscillating bar grids.

The Canada Department of Agriculture (8) described two other methods of separating stones and clods from potatoes which are by the use of an air-blast, or X-ray. An X-ray separating device has been developed by the Scottish Station of the N.I.A.E. in the U.K. It was stated that "It is proposed to have it marketed commercially as the Watson X-Septa."

Glaves and French (25) reported that the most widely used methods of clod and stone separation in potato harvesting are some form of sifting and rolling action on one or more tilted conveyors. The conveyors are tilted laterally with respect to the direction of conveying.

Gilfillan and Ramsay (23) reported that, to give the same amount of rolling action, a greater angle of tilt is necessary for rod conveyors than for flat belt conveyors. Glaves (24) reported that: "between rod aprons of different pitches or net clear space between rods, the smaller the pitch the greater the rolling action at any given angle of tilt". He also reported that with more nearly round varieties, the larger the tubers, the greater the tendency for the potatoes to roll back and cause damage to occur on either digger or harvester conveyors.

2.8.6 Bulk Transportation.

The general practice in Alberta is that the harvester delivers the potatoes into bulk transport vehicles. The delivery elevator of potato harvesters have a rubber covered rod link conveyor with flights attached to some of the links. The frame of the delivery elevator has one or two joints for adjusting the delivery height so that the drop from the end of the elevator into the vehicle is kept at a minimum.

The truck body has a "drop side" which is lowered to allow the drop between the end of the elevator and the bottom of the truck to avoid damage caused by excessive and avoidable drops.

2.9 STATE OF POTATO HARVEST MECHANIZATION IN ALBERTA

The use of combine harvesters capable of lifting a potato crop and delivering it in bulk commenced in 1953 in Alberta. Over half of farmers have stated that they buy machines, appreciating their limitations, and adapt them by trial and error to the peculiarities of their own crop and soil conditions.

2.9.1 Rate of Work.

The rate of working of a potato combine is affected by considerable variation in speed, row width, soil conditions, presence of clods, stones and weeds, and crop yield per acre.

West (58) writes that the forward speeds of operation of the potato harvesters in Maine and Michigan were of the order of 1.5 m.p.h. in good conditions, dropping to 1.0 m.p.h. in adverse conditions. Table 6 shows the rate of work of potato harvesters

in the U.S.A.

Table 6: Rate of Work of Potato Combine.*

Harvester	Acres per hour	Average Acres per hour
1 - row	0.24 to 0.36	0.28
2 - row	0.39 to 0.63	0.51

* Note: - Rate of work was based on 33 ins. row width and 20% time loss for turning at head lands and minor repairs.

Withers (60) reported in 1965 that, to harvest one acre of potato crop, 1.4 equipment operation hours were required in South Central Idaho. The rate of work was .72 acres per hour. Farm Mechanization (17) reported that the average acreage lifted per operator per seven-hour day is 0.34 with a harvester requiring four to five operators: whereas an elevator digger, which requires eleven to fourteen operators, can be expected to lift 0.15 acres per operator. Table 7 below shows the rates of work of two-row potato harvesters at the U.K. and reported by Farm Mechanization (18).

Table 7: Rate of Work of 2-row Harvesters.

Model	Overall rate of work, acres per hour
Catchpole Tow Row	0.36
Johnson Twin Major	0.29
Leeford Twinmaster	0.27

After the 9th International Potato Harvester Demonstration held at Hutton Moor Farm, Ripon, Yorks in October 1964, Farm Mechanization (18) reported that "...the output of two-row mahcines was relatively poor and they will have to improve considerably if they are to survive". This statement was based on Table 8 below comparing the rate of work of two-row and one-row potato harvesters.

Table 8: Rate of Work of 1-row Harvesters

Model	Overall rate of work, acres per hour
Grimme Stone Major	0.35
Whitsed RB	0.33
Johnson Major	0.32

According to the Farm Mechanization (18)

"The mood of growers has changed and they now clearly accept that complete harvesters must be used sooner or later if the crop is to continue to pay in face of increasing shortage of labour".

2.10 POTATO DAMAGE.

The Potato Marketing Board (43) stated that damage to potatoes while harvesting is caused by a combination of biological features of the crop and mechanical aspects of the machine. According to Preston (46) potatoes are more vulnerable to physical damage than either eggs or tomatoes.

"The Alberta Farm Guide" published by the Alberta Department of Agriculture (1) in 1967 contains no information either about the potato harvesting machines or the cause and level of damage at the field. The Department of Agricultural Engineering of the University of Alberta did some damage studies during the summer of 1966, which complements the results obtained from such studies conducted in the U.S.A. and the U.K.

2.10.1 Findings of some Recent Damage Studies in the U.S.A.

Farm Mechanization (17) contains the following tabulated result, obtained using different types of harvesting equipment in the U.S.A.

Table 9: Percentage of Crop Severely Damaged With the Use of Different Types of Harvesting Equipment in the U.S.A.

Method of Harvesting	Percentage Damaged by Weight	
	In Field	In Store
Potato Spinner	8.90	18.15
Digger	14.84	26.52
Combine	20.98	21.44

Cross (12) speculated that the elimination of bruises in Idaho potatoes would increase the income of Idaho potato growers by 18 percent and further noted that bruises caused more losses in the 1966 crop than either frost or freezing. These statements were based on a survey of processing, fresh packing and starch plants in 1966.

Finney, Hall and Thompson (19), citing studies done by Larsen, reported that growers injured an average of 42 percent of their potatoes during harvesting and, after grading, the amount was increased to about 54 percent.

Blasingame (7) quotes that, according to Dr. E.L. Nixon of the Pennsylvania State College, harvesting of potatoes is one of the '...weak links in the procedure', that is a point at which much tuber damage occurs.

2.10.2 <u>Findings of some of the Potato Damage Studies in the U.K.</u>

In 1965 studies in the U.K. made by the Potato Marketing Board (44) at Sutton Bridge Station indicated that 44.9 percent of potatoes were damaged at the time of harvest. Table 10 and Table 11 shows the damage by different methods of harvesting and handling.

Table 10: Potato Damage at Different Stages of Handling in the U.K.

Damage Assessment Point	1 TON BOXES % wt. in Damage Categories				Damage Index	17 CWT. BOXES % wt. in Damage Categories				Damage Index
	Undam.	Scuffed	Peeler	Serious		Undam.	Scuffed	Peeler	Serious	
As Lifted	55.1	16.0	13.6	15.3	164	52.3	18.8	16.2	12.0	152
Into Box	45.2	19.6	19.7	15.6	188	47.3	17.1	16.7	19.0	200
Arrival At Store	46.2	28.4	13.4	13.4	159	34.4	30.0	13.7	22.0	225

Table 11: Percentage Weight Damage in the Field and at the Clamp or Store after Transportation in the U.K.

System*	Undamaged		Scuffed		Peeler		Serious		Index	
	Field	Store	Field	Store	Field	Store	Field	Store	Field	Store
I	56.0	45.9	29.8	37.1	7.0	8.3	7.2	8.7	101	123
II	45.8	41.9	18.4	19.9	22.9	22.4	12.9	15.8	177	197
III	66.7	53.6	15.2	24.2	7.5	9.9	10.6	12.3	112	140
IV	54.9	29.6	20.0	31.3	8.9	14.2	16.2	24.9	160	248
V	71.4	57.8	19.0	28.0	4.2	5.1	5.4	9.0	70	106
Overall mean of all Systems I-V	58.5	46.5	20.5	28.0	10.0	11.5	11.0	14.0	127	160

* Note: Five Systems of Handling:

I. Complete harvester, delivery into field bulk trailer and unloaded at store or clamp.

II. Complete harvester, delivery into pallet boxes on trailer alongside, conveyed to bulk store or field clamp on trailer or on fork-lift truck.

III. Elevator digger, potatoes picked by hand into baskets, emptied into pallet boxes which were taken to bulk store or calmp on trailer or fork-lift.

IV. Elevator digger, potatoes picked by hand into baskets, emptied into field trailer and conveyed to bulk store or clamp, and

V. Complete harvester, delivery into farm trailer which in turn conveyed and unloaded to bulk store or clamp.

Farm Mechanization (18) presented the following information on potato damage at the time of harvest:

"When considering potato damage one tends to approach the subject from the harvesting end as the stage at which the harm is done but for some time there has been a greater awareness of the problem as a whole and it is now generally accepted that the reduction of damage does not start at the harvesting operation but at the time of cultivations before the crop is planted".

2.11 DETECTION OF DAMAGE IN THE POTATO.

Aspinwall, Hepherd and Hebblethwaite (5) and McLaren (40) reported that the detection of mechanical damage in potato tubers by eye alone is often difficult and, to assist the observer, chemical reagents are used which react with one or the other of the constituents exposed in the damaged tissue. Robertson (48) claimed that when a potato is damaged, either on the surface or in the deeper layers, the enzyme tyrosinase is exposed and catalyses the oxidation of the naturally occurring tyrosine to give a reddish-brown decomposition product. This product eventually produces the blue black colour of melanin. He also found that the above series of reactions are responsible for the colour changes from pink to grey-black which follow the peeling of potatoes. According to Robertson (48) the rate of development of this chain of reactions is slow, depends to a large extent on variety and, in some cases, is very difficult to detect. It is, therefore, unsuitable for the certain identification of damage.

Tyrosinase also catalyses the oxidation of certain other mono-hydric phenols such as phenol, para-cresol and catechol to produce highly coloured quinones. McLaren (40) reported that para-cresol is inexpensive and the resulting reaction is rapid even at low field temperatures. In most cases a period of ten to fifteen minutes is sufficient to produce the required intensity of colour. The para-cresol solution is stable and can be stored indefinitely, if desired.

2.12 DAMAGE ASSESSMENT.

The N.I.A.E. has developed a method for assessing the severity of potato damage. Codrington (11) writes that this method of potato damage assessment has been accepted by the European Association for Potato Research. The potato damage was assessed by the number of strokes required to remove the damage with a potato peeler set to remove one-sixteenth of an inch in one stroke. Table 12 below shows the severity and classification of damage.

Table 12: Severity and Classification of Damage.

Classification of damage	No. of strokes required to remove the damage by peeling with a potato peeler set to remove 1/16 ins. in one stroke.	Depth of damage in inches.
Skin damaged	1	less than 1/16
Slightly damaged	3	1/16 to 3/16
Seriously damaged*	more than 3	more than 3/16

*Note:- Broken and cut potatoes were included in the seriously damaged category.

2.13 DAMAGE INDEX.

The damage index for a potato sample is a number which will allow evaluation of the relative importance of the various grades of damage. According to West (57), it is an adaptation of a method suggested by a Canadian worker as far back as 1952 and by two Dutch workers in 1957. West (57) claims that this Damage Index is a measure of the economic importance of the total damage in a sample. The damage index for any potato sample can be obtained by multiplying the various damage percentages in a sample by the relative factors and adding them together. Table 13 below shows how the Damage Index can be obtained for a potato sample.

Table 13: Damage and Relative Factors.

Grades of damage	Multiplying factor	Example %	Example of T.D. I
Skin damaged	1	1	1
Slightly damaged	3	2	6
Seriously damaged	7	4	28
Total Damage Index by addition			35

PART III

INVESTIGATIONAL PROCEDURE

3.1 PROCEDURE

The procedure involved in the preparation of this project was as follows:

1. Reviewing literature
2. Selecting variables to be included in the study
3. Developing a technique for assessment of potato damage
4. Selecting farms
5. Preparing an experimental procedure
6. Conducting a pilot study.

3.1.1 Location of Research

Two-thirds of the Alberta potato acreage, as mentioned on page 8, is in the southern part of the province, with an additional one quarter around Edmonton. It was decided to conduct experiments in four farms in each of the two regions. Figure 4 on page 41 shows the location of farms from which data was collected. Table 14 on page 42 shows the details of farms studied.

3.1.2 Procedure Adopted for Data Collection.

The potato harvester test procedure developed at the National Institute of Agricultural Engineering, U.K., and reported by McLaren (40) shows that a row length of 100 yards or 300 feet was considered for harvester damage assessment trial. For the prupose of data collection and subsequent analysis for this thesis each 300-foot length was considered as a separate trial. Figure 5 on page 43 shows the field layout for each experiment.

Figure 4. Map showing the location of farms from which data was collected.

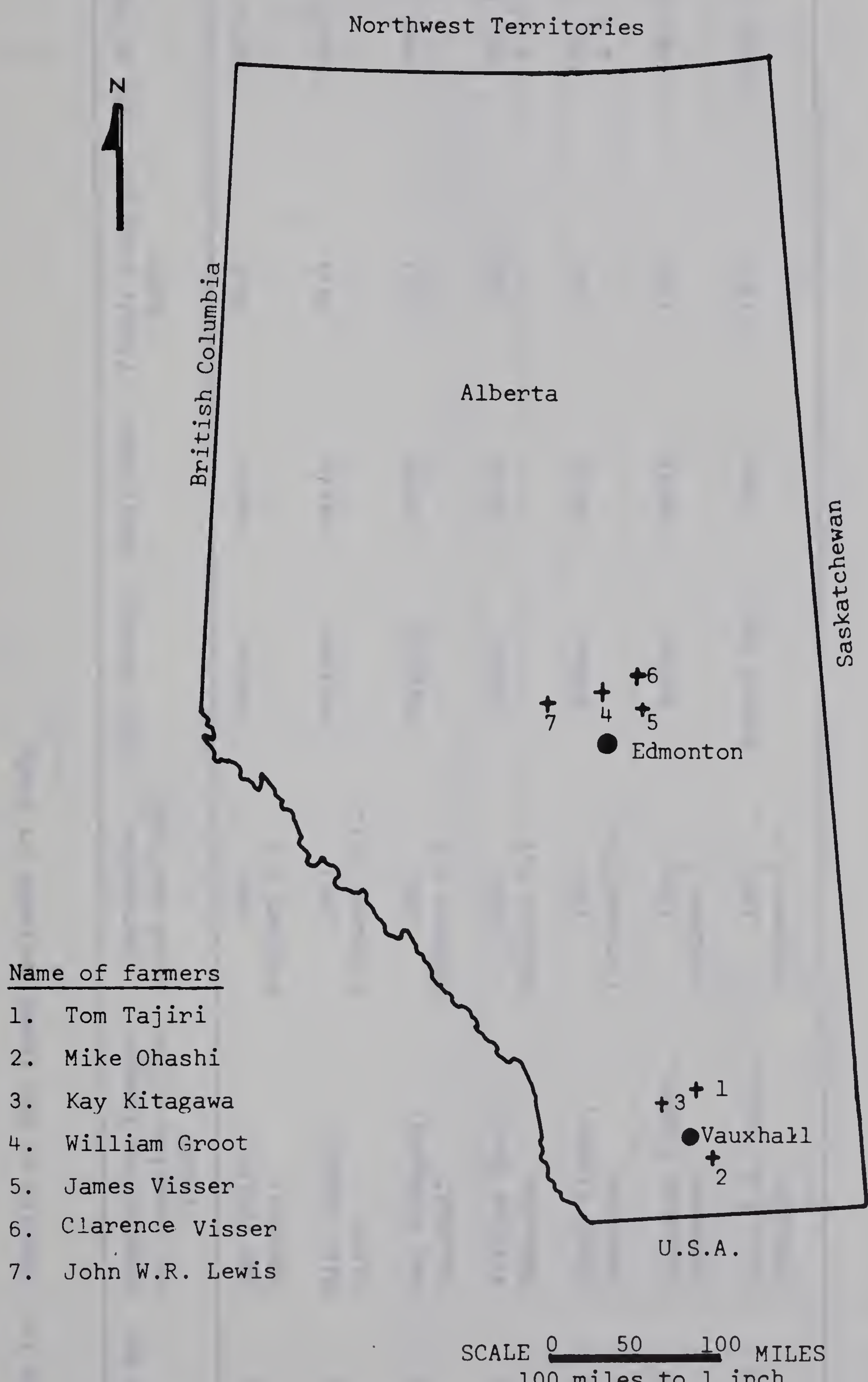
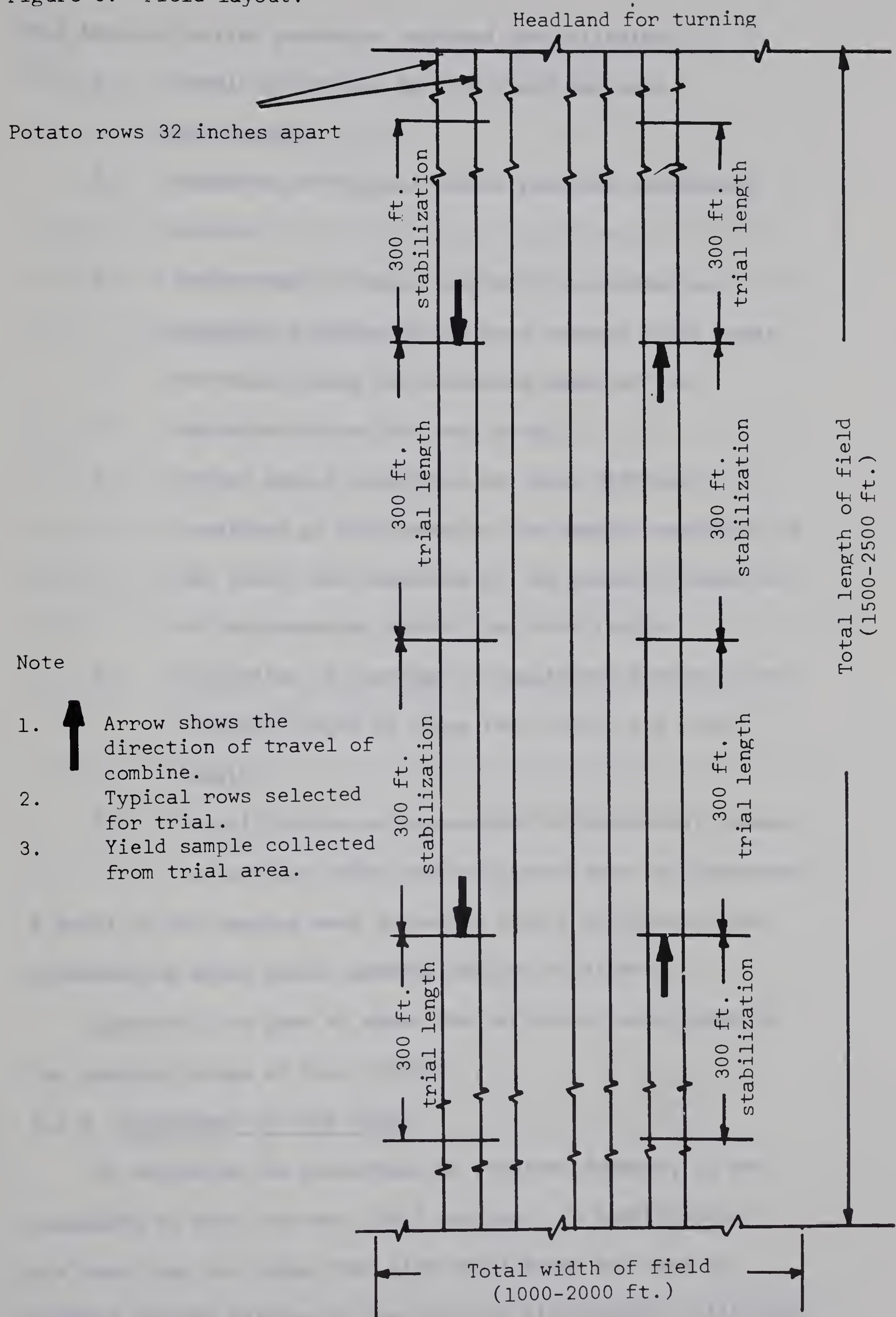


Table 14: Details of the Farms Included in Study.

Farm No.	Name of the farmer and location of the farm*	Harvester make and type	Crop Variety	Early/Late	Yield, tons per acre	Date of Harvest
1	Tom Tajiri, Vauxhall	1964 Dahlman S.P.	Warba	early	15.6	Sept. 5
2	Mike Ohashi, Taber	1967 Lockwood Pull	Norland	early	23.4	Sept. 6
3	Kay Kitagawa, Vauxhall	1964 Dahlman S.P.	Norgold	early	12.1	Sept. 6
4	William Groot, Edmonton	1967 Dahlman S.P.	Warba	early	7.9	Aug. 10 & 11
5	James Visser, Edmonton	1961 Farmhand Pull	Warba	early	11.5	Aug. 2 & 3
6	Clarence Visser, Edmonton	1964 Dahlman S.P.	Warba	early	12.2	Aug. 4
7	John W.R. Lewis, Edmonton	1967 Dahlman S.P.	Netted Gem	late	13.8	Oct. 7

* Hereafter farms will be referred to by numbers.

Figure 5. Field layout.



The data collection procedure included the following:

1. Sample collection for the yield per acre assessment.
2. Selection of typical potato rows for conducting trials.
3. Measurement of trial lengths by providing an adequate distance in the rows between trial areas for stabilizing the operating speed of the harvester before the next trial.
4. Potato sample collection at three different locations of the harvester for damage assessment of the trial, and recording of the speed of operation of the harvester within the trial length.
5. Collection of leavings or ungathered potatoes from a sample length of three feet within the trial length.
6. Classification and assessment of mechanical damage to potatoes which were collected from the harvester.

A total of 303 samples were collected from 7 different farms representing major potato growing regions of Alberta.

Appendix F on page 81 shows the variables encountered at the planning stage of this project.

3.1.3 Assessment of Crop Yield.

To determine the percentage of potatoes damaged, it was necessary to know the crop yield per acre. A prefabricated six feet long and three feet wide metal frame was used to isolate typical patches of the crop for yield sample collection.

All the potatoes in that area were collected and labelled as one yield sample.

3.1.4 Assessment of Leavings.

The frame was also used to isolate a typical patch from a trial length, on which assessments of potatoes left in the ground were made. Table 23 on page 61 shows the leavings found.

3.1.5 Forward Speed of Operation.

The recommended forward speed of potato harvesting, according to Sparks (52) was 1.5 mph for normal Idaho conditions. At the pilot study it was observed that the forward speed of operation was between 1.5 mph and 2 mph. The information gathered during the pilot study and the recommendations of Sparks (52) was used as a guide to prepare the following table 15.

Table 15: Suggested Forward Speed of Operation for Nine Trial Runs on Each Farm*.

Trial No.	Forward Speed in mph		
1	0.50	-	0.74
2	0.75	-	0.99
3	1.00	-	1.24
4	1.25	-	1.49
5	1.50	-	1.74
6	1.75	-	1.99
7	2.00	-	2.24
8	2.25	-	2.49
9	2.50	-	2.75

* Note: The above quarter mile speed range between trials were selected to accomodate a wider range within the speed limit set for speed versus damage percentage correlation computations.

3.1.6. Sample Collection for Damage Assessment.

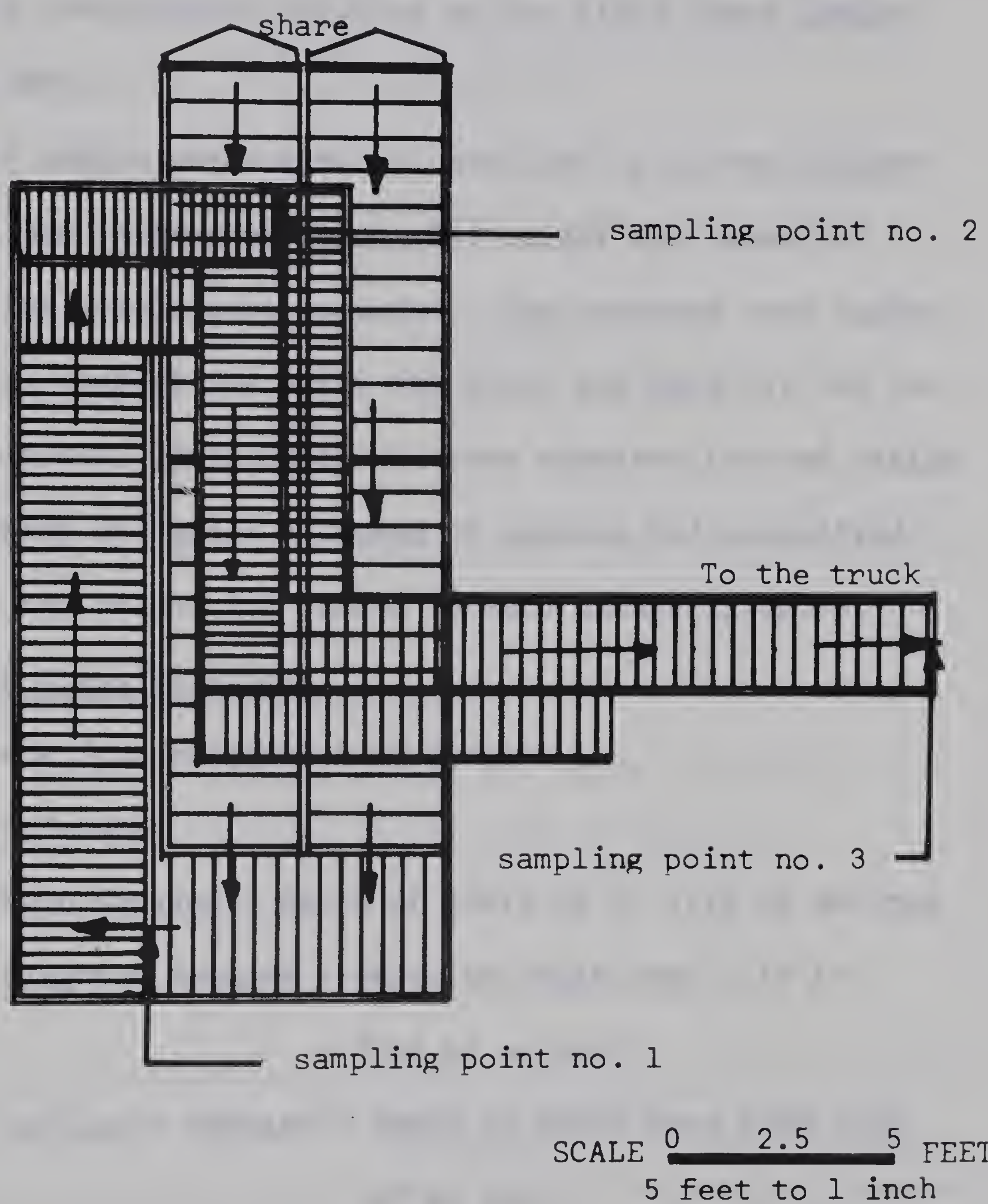
To observe the damage caused by the harvester, three samples of potatoes were collected from three different locations on the harvester for each trial. Figure 6 on page 47 shows these locations. Table 16 below shows the order in which the potato samples were numbered. Appendix D on page 79 also shows their location in a flow process chart.

Table 16: Sample Numbers and Their Location.

	Location on the harvester
Sample No. 1	Between rear cross conveyor and side elevator
Sample No. 2	Junction between front cross conveyor and picking table
Sample No. 3	End of delivery conveyor.

Potato samples were collected by holding plastic bags between the conveyors. Approximately five pounds of potatoes were collected per sample. Care was taken not to damage any tubers during collection and subsequent analysis.

Figure 6. Plan View of a Potato Combine Showing Flow of Potatoes.



Note: Arrows show the direction of flow of potatoes on the harvester starting from the share to the truck.

3.2 TESTING FOR DAMAGE.

To assist in detecting mechanical damage to potato tubers para-cresol was used. The two-percent reagent was prepared by dissolving ten grams of sodium hydroxide in 250 ml of water and adding 50 grams of para-cresol. About 2.5 liters of water was added to this concentrated solution at the field where damage testing was done.

The test sample was soaked in water for up to two minutes and any soil was removed by hand. The weight and number of potatoes in the sample were recorded. The potatoes were soaked in para-cresol reagent one after the other and laid out for ten to fifteen minutes. Each tuber was then examined for red stains and the severity of damage assessed by peeling and classified according to the weight and number in each damage category.

3.2.1 Damage Classifications.

There were four categories of damage:

1. Undamaged
2. Skin damaged - depth of stain up to 1/16 of an inch
3. Slightly damaged - depth of stain from 1/16 to 3/16 of an inch
4. Seriously damaged - depth of stain more than 3/16 of an inch.

The data collected were used for the following analyses.

1. Percentage of potatoes damaged.
2. Total damage index.
3. Regression analysis between damage percentage and forward speed variables.
4. Relationship between the weight of damaged and the undamaged potato.

PART IV

RESULTS AND DISCUSSION

4.1 RESULTS.

The following results were obtained from analysis of the collected data from six early harvested farms and one late harvested farm. For the purpose of explanation, the results will be listed under the following headings:

1. Percentages of potatoes damaged in each category.
2. Size of damaged potatoes.
3. Damage versus length of conveyor.
4. Damage versus forward speed of operation.
5. Leavings per acre.

Appendix A on page 73 contains typical raw data collected from one farm.

4.1.1 Percentages of Potatoes Damaged.

Table 17 below shows the average percentage of early potatoes damaged in the fields at the time of harvest in Edmonton and Southern Alberta.

Table 17: Early Potatoes Damaged at Harvest Time.

Area	Percentage Damaged by weight	Number of farms studied
Edmonton area	39.0	3
Southern Alberta	29.4	3

In farm No. 7, a late crop was harvested and the damage was found to be 40.7 percent. The farmer harvested six rows at a time after windrowing. Potato samples collected from the windrowed crop showed damage amounting to 14 percent.

Table 18 below shows the percentage of potatoes damaged in each farm and the classification of damage. It would appear that about 35 percent of the potatoes are being damaged in the field at the time of harvest. The pictorial representation of the damage percentages, Figure 7 on page 51 shows a comparative assessment of different classifications of damage in the seven farms in question. The relative economic importance of the various classifications of potato damage is shown by Figure 8 on page 52.

Table 18: Potato Damage in each Farm and the Classification of Damage.

Farm No.	Yield T/A	Skinned %	Slight %	Serious %	Total Damage %	Unmarketable Produce%*
1	15.6	13.1	17.9	27.3	58.3	45.2
2	23.4	10.7	8.9	5.2	24.8	14.1
3	12.1	20.9	7.7	11.1	39.7	18.8
4	7.9	10.2	11.2	18.0	39.4	29.2
5	11.5	16.5	17.9	25.9	60.3	43.8
6	12.2	14.2	20.7	22.8	57.7	43.5
7**	13.8	25.4	19.6	21.2	66.2	40.8

Note: * Slightly and seriously damaged potatoes fall below the standards of the Federal Government for domestic supply or for export.

** The farmer used a windrower and harvested 6 rows at a time. Samples collected from the windrowed crop indicate a damage of 14%. This was the only main crop.

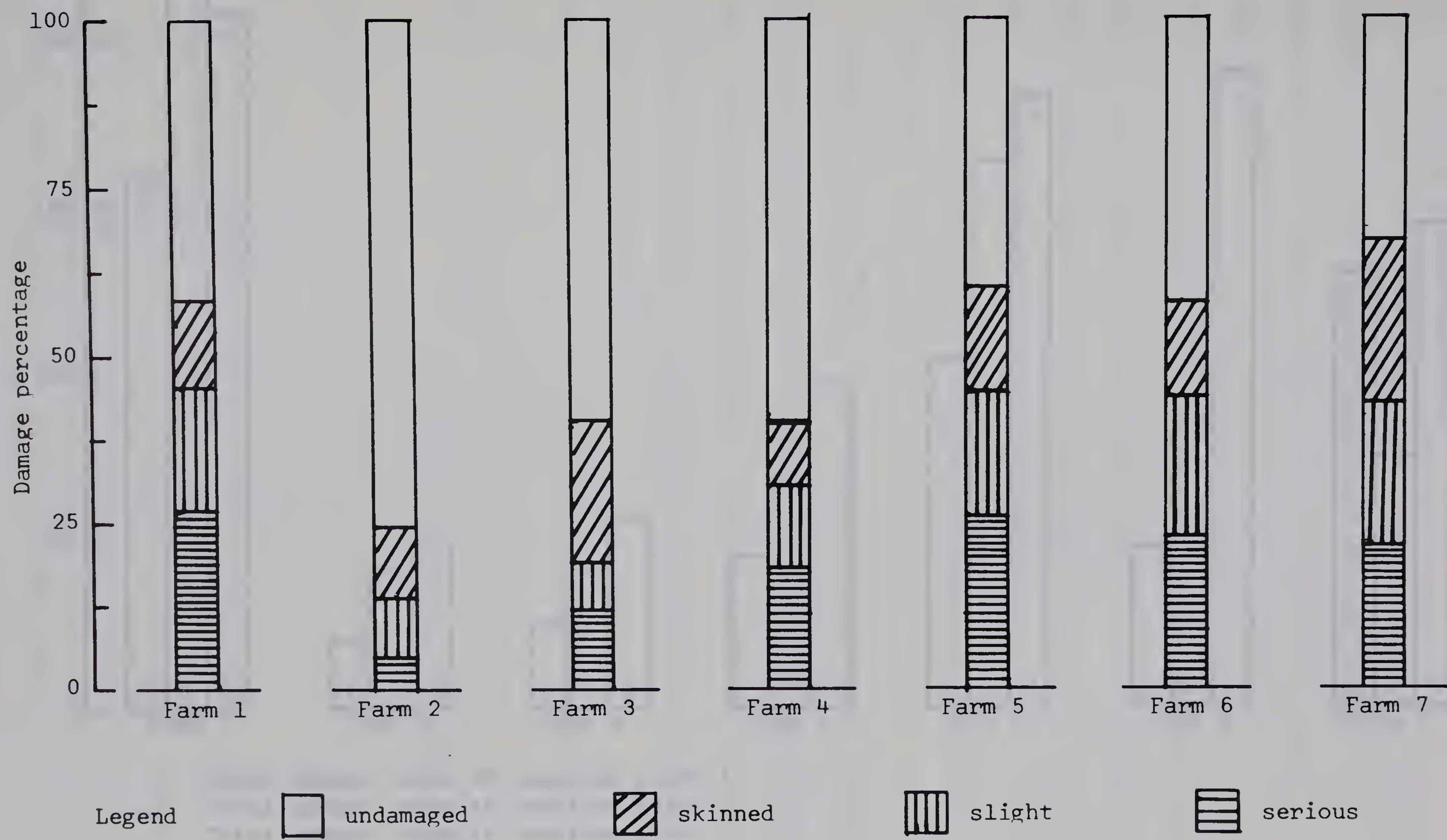
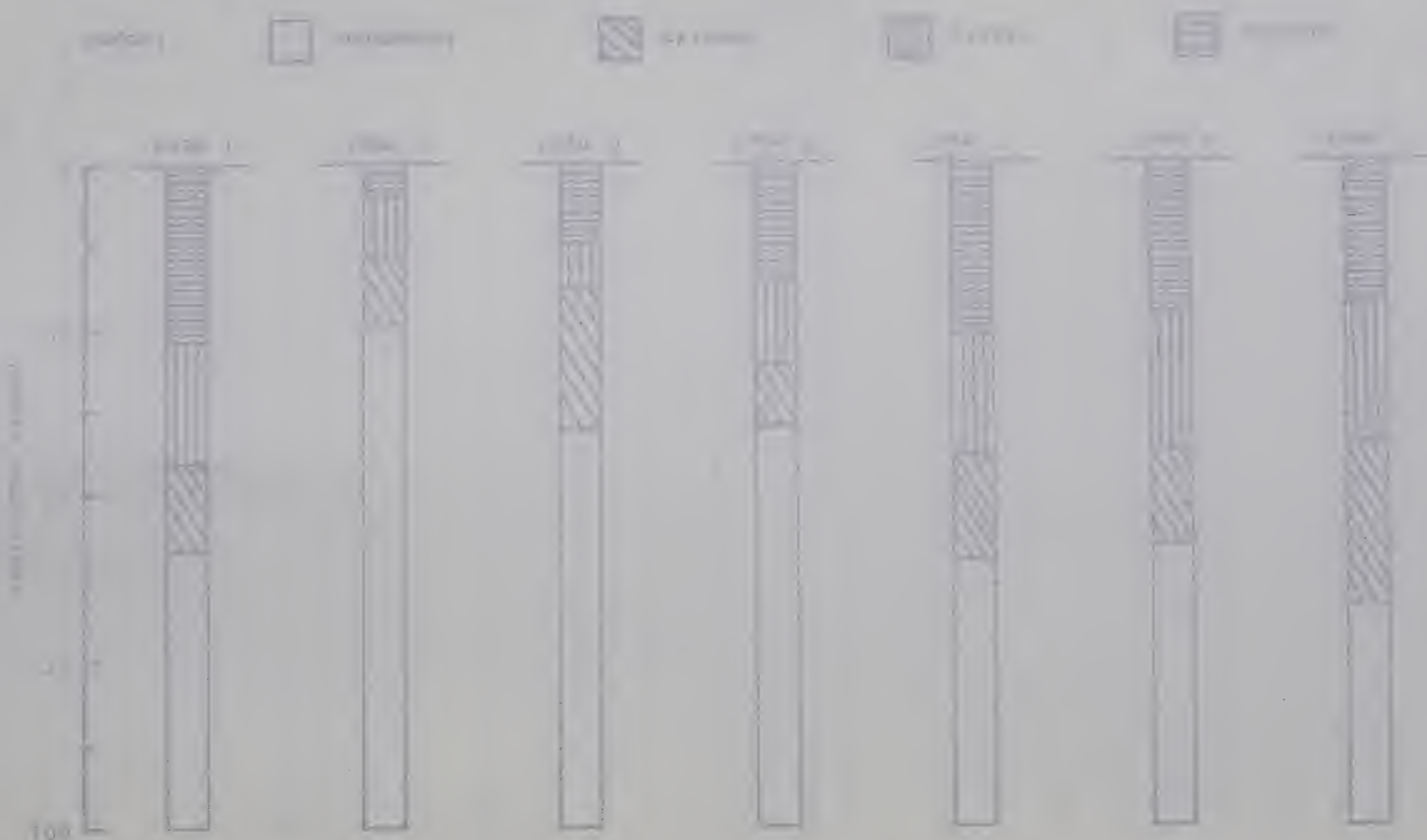


Figure 7. Classification of Damage.



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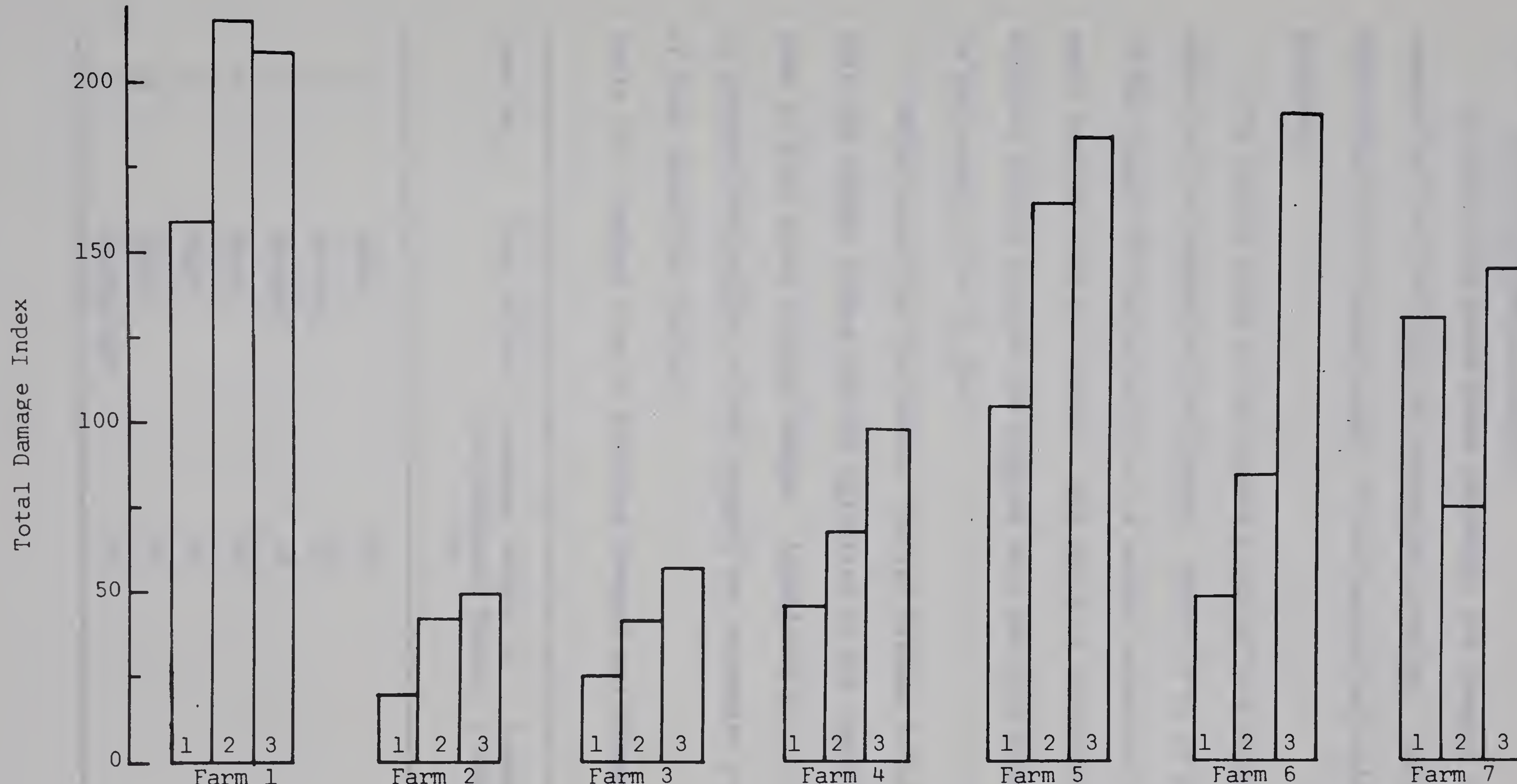


1. Total damage index at sampling point 1.
2. Total damage index at sampling point 2.
3. Total damage index at sampling point 3.

Figure 8. Total Damage Index (by weight).

4.1.2 Size of Damaged Potatoes

In six of the seven farms selected, the damaged tubers were heavier by 1 to 20% than the undamaged potatoes. Table 19 below shows the average weight of the damaged and undamaged potatoes.

One reason could be the narrow pitch of the conveyor links which is 1.56 inches to 1.88 inches. About 70 to 80 percent of the length of the conveyors of a potato harvester is at an angle ranging from 10° to 35°. The angle of elevation of critical points such as the digging unit and side elevator is in the order of 25° to 35°.

While elevating the potato, the gap between links cannot hold the larger tubers and the agitation of the conveyor causes them to roll down, causing damage. Appendices C_1, C_2, C_3, & C_4 contain the weights of the damaged and undamaged potatoes of four varieties studied.

Table 19: Average Size of Potatoes Damaged and Undamaged.

Farm No.	Crop Variety	Average Weight of an Undamaged Tuber, lb.	Average weight of a Damaged tuber, lb.
1	Warba	.32	.37
2	Norland	.32	.32
3	Norgold	.35	.35
4	Warba	.26	.28
5	Warba	.26	.26
6	Warba	.33	.34
7	Netted Gem	.43	.48

4.1.3 Damage Versus Length of Conveyor.

Irrespective of the make and model of the harvester, on a per-foot basis the primary and secondary conveyors were found to cause more damage than the rest of the machine. Table No. 20 on page 55 shows that, as the potato moves further from the digging section the damage caused by an increment of conveyor length is decreased.

A minimum damage index of 0.95 per-foot run at the digging unit was observed with a 1967 Lockwood potato harvester, and a maximum index of 6.67 per foot run was noted in testing a 1964 Dahlman model. In each foot of run of conveyor on all harvesters it would appear that an average damage index of 2.00 resulted.

Table 21 on page 56 contains the total damage index at various sampling points on the machine.

Table 20: Damage at Different Sections on the Machine on a per foot Basis.

Farm No.	Harvester Model & Year	Total Damage Index per ft. run at digging section	Total Damage Index per ft. run at elevating section	Total Damage Index per ft. run at delivery section	Total Length of conveyors of harvester in ft.
1	Dahlman 1964	6.67	5.12	2.82	74.0
2	Lockwood 1967	0.95	0.87	0.65	72.5
3	Dahlman 1964	1.08	0.96	0.84	72.5
4	Dahlman 1967	1.88	1.71	1.34	72.5
5	Farmhand 1961	4.52	4.23	3.35	54.0
6	Dahlman 1964	2.00	1.98	2.57	74.0
7	Dahlman 1967	5.42	2.25	2.01	72.5

Table 21: Total Damage Index at Various Sampling Points on the Machine

Farm No.	Damage Index (Wt)			Damage Index (No)		
	Sampling Point 1	Sampling Point 2	Sampling Point 3	Sampling Point 1	Sampling Point 2	Sampling Point 3
1	160	220	209	172	160	180
2	20	40	47	27	54	57
3	26	42	61	25	38	58
4	45	68	98	49	46	78
5	105	165	185	98	161	187
6	49	86	190	50	76	153
7	130	74	146	141	88	115

4.1.4 Damage Versus Forward Speed.

Table 22 below shows the average forward speed of operation and damage occurring in the seven farms investigated.

The correlation coefficients were computed for a speed versus damage index variable for all farms. From the observed data it would appear that the best fit curve is of a parabolic nature. Correlation coefficients of .45, .51, .39, .55, .11, .33 and .18 were obtained from seven farms respectively for the equation $y = a + bx + cx^2$. That is the variation in speed accounts for 30% of the variation of damage.

Table 22: Forward Speed of Operation Versus Damage.

Farm No.	Average Speed mph	Average Damage Index by wt.	Average Damage % by weight (unmarketable produce)	Correlation coefficients
1	1.8	209	45.2	.45
2	1.9	47.	14.1	.51
3	1.7	61.	18.8	.39
4	1.8	98	29.2	.55
5	2.4	185	43.8	.11
6	1.7	190.	43.5	.33
7	1.9	146	40.8	.18

It would appear that there is not a definite relationship between the speed of operation and damage done. The following extracts show the wide variability of damage incurred with

variable speeds, farms and varieties, and the inconsistencies of the data collected.

4.1.5 Farm No. 1

Warba variety, Dahlman (1964) combine. 54.2 percent damage resulted at 1.4 mph. and 47.3 percent at 3.6 mph. Yet at 2.1 mph. it was 48.6 percent and in another trial at 1.2 mph. it was 47.2 percent.

4.1.6 Farm No. 2

Norland variety, Lockwood Mark VI (1967) combine.

At 1.2 mph. the damage was 56.4 percent and at 2.7 mph. it was only 53.0 percent. On another occasion at 1.6 mph. the damage was 25.3 percent and at the next trial, with 1.6 mph. damage was only 6.1 percent.

4.1.7 Farm No. 3.

Norgold variety, Dahlman (1964) combine.

At 0.7 mph. the damage was 35.5 percent whereas at 2.5 mph. it was only 16.5 percent. In the next trial, at 2.5 mph. the damage was 37.6 percent and in another trial at 1.7 mph. the damage was 19.3 percent. At 1.7 mph. damage was 23.5 percent.

4.1.8 Farm No. 4.

Warba variety, Dahlman (1967) combine.

8.7 percent damage was recorded at 1.2 mph. whereas at 1.2 mph. it was only 7.8 percent. On another occasion at 1.6 mph. the damage was 27.3 percent and at 1.6 mph. it was 30.5 percent. Interestingly enough, at 1.2 mph. there was damage of 38.4 percent.

4.1.9 Farm No. 5

Warba variety, Farmhand (1961) combine.

At 2.5 mph. the damage was 27.0 percent and at 2.5 mph. it was 32.0 percent. In another trial, at 2.5 mph. damage was 10.0 percent and at 2.2 mph. it was 69.0 percent.

4.1.10 Farm No. 6

Warba variety, Dahlman (1964) combine.

At 1.5 mph. the damage was 14.0 percent and at 1.5 mph. for the next trial, it was 22.3 percent. On another test at 2.7 mph. the damage was 53.0 percent and at 1.2 mph. it was 56.4 percent. Paradoxically, at 1.6 mph. the damage was only 6.1 percent.

4.1.11 Farm No. 7

Netted Gem variety, Dahlman (1967) combine.

In one trial, at 1.2 mph. the damage was 37.9 percent, whereas at 2.1 mph. it was 37.0 percent. In another trial, at 2.2 mph. the damage was 74.3 percent and at 2.2 mph. it was only 16.3 percent.

Reviewing the speeds of operation related to damage, it would appear that greater damage occurs at a slow speed than at a higher speed of around 2 mph. In most cases there was an increase in the damage percentage after a certain range in forward speed, but there seems to be no direct relationship between the increase in speed and a reduction in damage. For this reason attempts were made to identify parabolic relationships.

4.1.12 Multiple Linear Regression.

The method outlined by Fisher (20) and Snedecor (51) was used for analysis. Regression analysis for the speed versus damage percentage variables were performed using a programme of the University of Alberta Computing Centre. The regression equation had the following general form.

$$Y = a + bx + cx^2$$

where Y = Percentage damage.

X = speed of operation in mph.

a = constant

b,c = multiple partial regression coefficients.

The best correlation obtained was .55. It shows that a maximum of only 30% of the variation of damage can be explained by the variation of speed.

4.1.13 Leavings per Acre.

Ungathered potatoes are leavings and are found on the top of the ground. Table 23 shows the average percentage of ungathered potatoes.

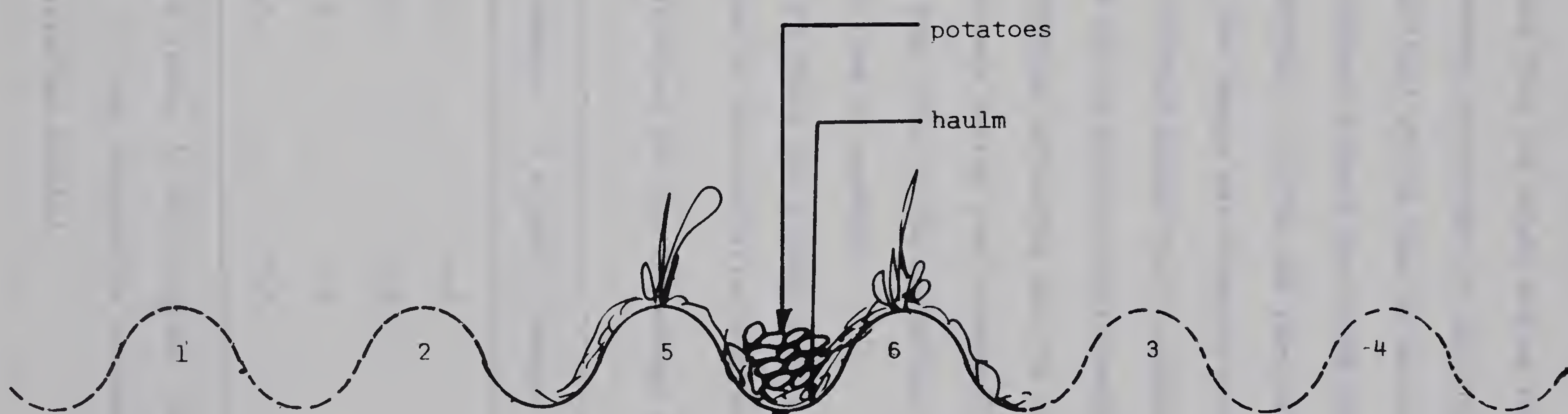
Table 23. Percentage of leavings by weight.

Farm No.	% Leavings by weight
1	4.5
2	1.4
3	5.7
4	5.6
5	9.2
6	3.7
7	10.6

It would appear that an average of 5.8 percent of the total weight of potatoes was left in the ground, ungathered, on early crop-harvested farms. Ungathered potatoes totalled 9.2 percent of the entire crop in farm No. 5. In the 1967 season, farm No. 5 was the first to harvest "new" potatoes in the Edmonton area. The crop was immature and the potato harvester was six years old. However, average percentages of ungathered potatoes in the other five farms where new potatoes were also harvested, was found to be 4.1 percent.

In farm No. 7 the leavings percentage was 10.6. At an early stage of the study in this farm, it was realized that the leavings were more compared to the farms studied previously. Close observations revealed the following possible reason for the 10.6 percent leavings. Figure 9 shows the location of windrowed potatoes with respect to haulm. The windrowed potatoes were above the haulm, which acted as a fence. When the potatoes and haulm were passed over the conveyors, those potatoes left above the haulm were thrown out of the combine and left ungathered in the field.

Figure 9: Location of Windrowed Potatoes with respect to haulm.



Rows 1,2,3 & 4 harvested and deposited between rows 5 & 6, which is to be harvested by combine.

4.2 CONCLUSIONS.

The conclusions from the study are as follows:

1. The average percentage of early potatoes damaged in the field at the time of harvest in Edmonton and Southern Alberta was 39.0% and 29.4% respectively. In the one farm harvesting a late crop, the damage was found to be 40.8%.

   It would appear that in Alberta an average of 35% of the potato crop is being damaged in the field during harvesting and the provinces' potato growers are losing over three million dollars every year, due to the mechanical damage to potatoes at the time of harvest.

2. Table 24 shows the average percentage of damaged potatoes in four varieties studied:

Table 24: Crop Varieties and the Percentage of Damage.

Variety	% skin damaged	% slightly damaged	% seriously damaged
Warba	13.7	16.2	23.4
Norland	10.7	8.9	5.2
Norgold	20.9	7.7	11.1
Netted Gem	25.4	19.6	21.2

From the above table, it would appear that the Norland potato variety is less susceptible to damage than any of the other three varieties studied.

3. The average weight of a damaged potato was up to 20% heavier than the average weight of an undamaged potato. Figure 10 on page 65 shows the relationship between the weight of damaged and undamaged potatoes. From the figure, it would appear that the heavier the potato, the more likely it is to be damaged.

4. Each foot run of the harvester conveyor resulted in an average damage of two index points. The damage caused by the digging section of the harvester is more than that of any other section of the machine. Martin and Humphrey (38) claim that one should "allow potatoes no free fall of over 6 inches". Therefore it was concluded that the twelve to sixteen inch drop between the primary and secondary conveyors of the harvesting machines might be one of the causes of damage.

5. If the general habit of growth of potatoes in Alberta is much the same as Bailey (6) indicated it would appear that the farmers keep the share of the combine to harvest around B' - B' as shown in Figure 1 on page 12. When the excavated potato ridge reaches the primary conveyor, the potato is in direct contact with the rod links of the conveyor. In a potato harvester the height of agitation at the digging unit conveyor may be up to six inches. The weight of the topsoil on the potatoes coupled with the movement of the rod links of the conveyor, results

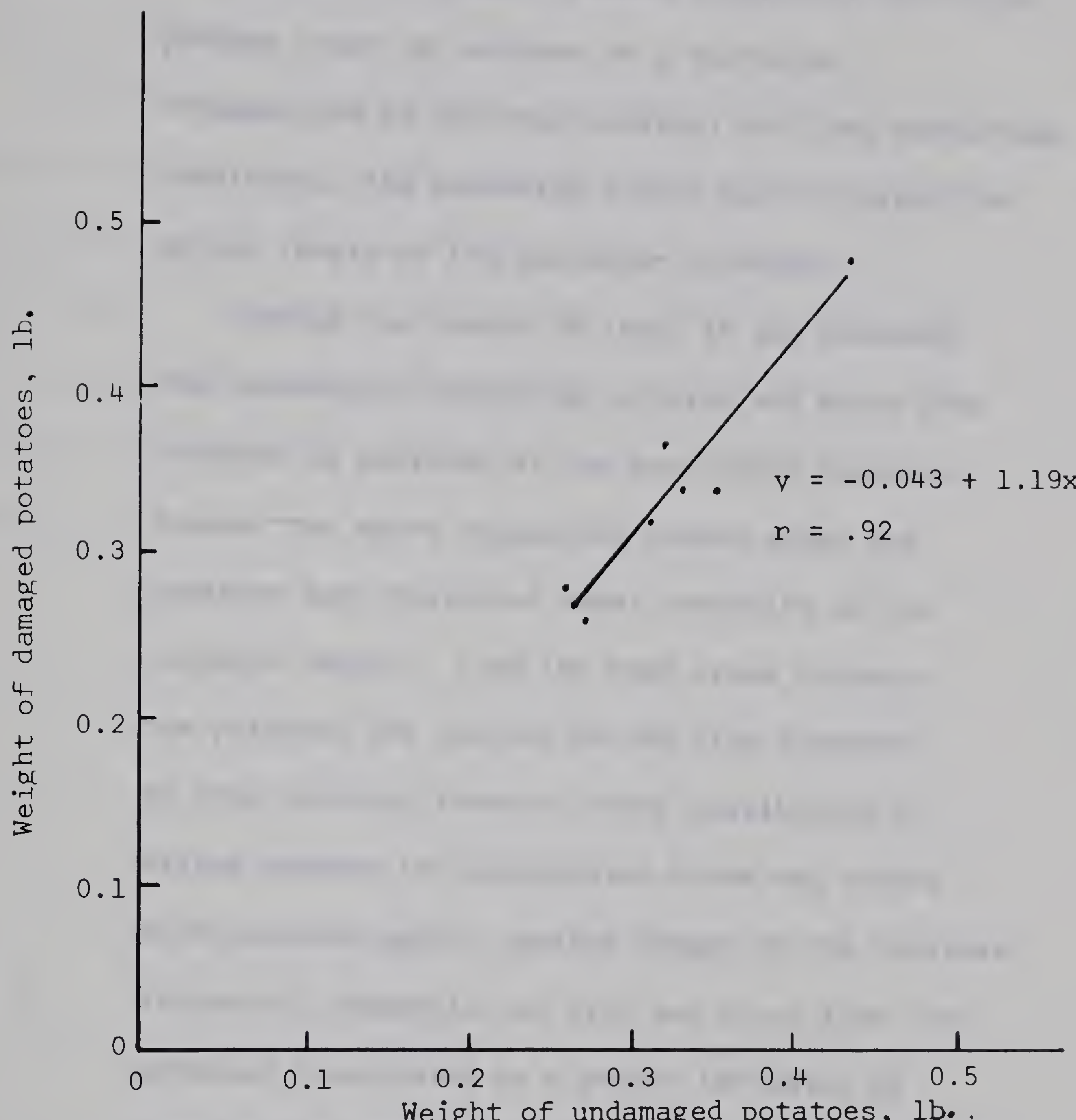


Figure 10. Relationship between the weight of the undamaged and damaged potatoes

in a hammering action on the potatoes which causes damage.

6. The Figure 11 on page 79 shows a material-type flow-process chart of potatoes on a harvester. Irrespective of the crop variety, soil and harvesting conditions, the harvested potato has to travel the entire length of the harvester conveyors.

   During the course of study it was observed that mechanical separation of clod and stone from potatoes is achieved at the rear cross conveyor. However the above separation occurs after the potatoes have travelled about one-third of the conveyor length. From the rear cross conveyor the potatoes are carried on the side elevator. At this conveyor there is every possibility of mixing between the unseparated clods and stones with potatoes again, causing damage to the potatoes.

7. Mechanical separation of clod and stone from the potatoes is achieved on a potato harvester by changing the angle of tilt of one or more conveyors, depending upon the soil conditions. The mechanism designed to change the angle of tilt is inconveniently positioned for manual operation since it is fitted near the conveyor, far out of reach of the harvester operator. This results in an unnecessarily high damage rate.

Finally it may be pointed out that once a farmer was made aware of the damage to his crop, this damage was reduced by as much as 50 percent.

With functional improvements in design and details of construction and more careful operation of potato harvesters, the farmer will be able to deliver quality potatoes with less damage. The several differences in current design and the prospects for further development seem to indicate that current potato harvester designs have not yet reached full maturity.

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APPENDIX A: Raw Data Collected from Farm 1, Selected as Typical Data. (Weights in lb.)

Trial	Sample No.	Wt. of sample	No. of sample	Wt. of damaged	No. of damaged	Wt. of skinned	No. of skinned	Wt. of slight	No. of slight	Wt. of serious	No. of serious	Wt. of leavings	Forward speed mph
	1	4.37	8	2.65	6	2.00	4			.63	2	1.06	1.2
1	2	3.00	10	.44	2	.13	1	.38	1				
	3	3.69	11	2.50	8	.31	1	1.31	3	1.00	4		
	1	3.25	11	2.25	8	.87	4	.75	2	.50	2	.76	1.5
2	2	2.75	15	.94	4	.44	2	.50	2				
	3	4.19	12	3.13	9	1.88	5	.19	1	1.06	3		
	1	3.00	6	.88	2			.88	2			.53	1.8
3	2	3.38	11	2.31	7	.63	2	.63	2	1.13	3		
	3	4.56	9	4.13	8	1.19	3	.56	1	2.13	4		
	1	4.44	11	3.06	5	.94	2	.81	2	1.13	1	.61	1.8
4	2	3.19	13	2.98	4			.56	3	.25	1		
	3	5.63	21	1.69	6	.69	3	1.06	3				
	1	3.13	12	.13	1	.13	1					.45	1.4
5	2	3.38	11	1.44	5	.19	1	.50	2	.63	2		
	3	3.38	11	1.18	3	.63	1	.13	1	.31	1		
	1	3.50	11	2.50	6	.38	2	.38	2	.50	3	.45	1.4
6	2	3.19	11	1.31	4	.19	1	.68	2	.38	1		
	3	4.00	12	2.00	5	.25	1	.69	4				
	1	4.50	11	1.50	4	1.50	4			1.50	4	.38	1.3
7	2	2.75	9	1.56	5	.31	1	.94	3	.38	1		
	3	5.88	21	1.94	6	.19	1	.44	1	1.38	4		
	1	3.56	12	1.25	3			.50	1	.63	2	.38	1.3
8	2	3.75	10	.94	2			.19	1	.75	1		
	3	4.62	15	1.75	6	.31	1	.81	3	.69	2		
	1	3.69	7	1.63	3	.81	1			.81	2	.23	2.5
9	2	3.25	10	2.56	5	.19	1	.63	1	1.75	3		
	3	4.56	16	2.81	9	.13	1	.75	2	1.94	6		
	1	4.00	11	1.88	5	.50	2			1.38	3	.98	3.6
10	2	3.19	9	1.31	3					1.31	3		
	3	4.31	12	2.31	6	.63	1	.38	1	1.38	4		
	1	3.25	8	2.38	5			.81		1.56	3	Nil	1.5
11	2	3.25	10	.56	2	.19	1	.38	1				
	3	4.69	20	1.81	6			.31	1	1.56	5		
	1	4.06	16	1.19	5			.25	3	.31	2	1.13	1.9
12	2	3.69	11	2.44	6			1.25	4	1.38	2		
	3	4.38	15	2.13	6			.25	1	1.44	5		
	1	4.00	10	.56	2	.25	1	.31	1			.15	1.8
13	2	3.69	13	1.56	5			.38	2	1.18	3		
	3	5.44	15	2.06	5			1.00	3	1.06	2		
	1	4.00	12	2.44	7	.38	1	.63	3	1.44	3	.98	1.5
14	2	3.75	11	1.44	3			.75	2	.75	1		
	3	3.56	16	.63	2	.06	1	.56	1				
	1	2.13	5	.88	2			.50	1	.38	1	.45	2.1
15	2	3.18	11	2.63	7			1.06	4	1.56	3		
	3	6.44	21	2.31	8			1.19	4				

APPENDIX B: Total Damage Index, Farm No. 1 (Typical Result)

Trial No.	By Weight TDI at sampling point 1	TDI at sampling point 2	TDI at sampling point 3	By Numbers TDI sampling point 1	TDI at sampling point 2	TDI at sampling point 3
1	143	42	305	23	40	345
2	177	70	236	218	53	242
3	87	308	387	100	263	345
4	254	109	69	136	123	57
5	4	182	94	8	192	100
6	34	153	133	236	128	108
7	100	209	189	108	190	153
8	165	162	164	142	100	160
9	176	440	349	214	250	306
10	252	289	263	210	234	266
11	410	40	253	337	40	190
12	73	363	281	143	236	253
13	30	375	192	40	207	153
14	308	200	49	258	118	25
15	195	370	178	200	300	191

Note: Total Damage Index Computed From Raw Data (Appendix A).

APPENDIX C_1: Farm No. 1. Size of potatoes. Crop variety - Warba.

No.	Average weight of undamaged potatoes in the sample	Average weight of damaged potatoes in the sample
1	.55	.44
2	.30	.22
3	.34	.31
4	.29	.31
5	.18	.23
6	.35	.35
7	.50	.44
8	.31	.33
9	.51	.52
10	.40	.61
11	.25	.72
12	.27	.28
13	.26	.13
14	.31	.29
15	.31	.40
16	.32	.42
17	.29	.33
18	.33	.40
19	.40	.38
20	.31	.31
21	.28	.32
22	.28	.42
23	.38	.47
24	.31	.29
25	.53	.54
26	.33	.54
27	.41	.31
28	.36	.38
29	.35	.44
30	.36	.39
31	.41	.48
32	.33	.44
33	.23	.39
Average	.32	.37

Note: This table was prepared from the data collected for damage assessment and shows 69.5% of the individual sample has damaged tuber heavier.

APPENDIX C_2: Farm No. 2. Size of potatoes. Crop Variety - Norland.

No.	Average weight of an undamaged potato in the sample	Average weight of a damaged potato in the sample
1	.36	.31
2	.46	.46
3	.29	.34
4	.29	.47
5	.30	.15
6	.32	.33
7	.26	.25
8	.38	.22
9	.23	.28
10	.30	.18
11	.37	.27
12	.26	.28
13	.33	.31
14	.34	.44
15	.40	.44
16	.35	.06
17	.40	.41
18	.28	.14
19	.34	.34
20	.38	.25
21	.32	.34
22	.33	.34
23	.29	.33
24	.31	.06
25	.28	.22
26	.26	.27
Average	.32	.32

Note: This table was prepared from the data collected for damage assessment and shows 53.8% of the individual sample has damaged tuber heavier.

APPENDIX C_3: Farm No. 3. Size of potatoes. Crop variety - Norgold.

No.	Average weight of an undamaged potato in the sample	Average weight of a damaged potato in the sample
1	.34	.88
2	.33	.27
3	.39	.44
4	.39	.58
5	.33	.06
6	.31	.34
7	.41	.56
8	.35	.44
9	.35	.26
10	.44	.35
11	NR	NR
12	.35	.28
13	.42	.22
14	.30	.34
15	.25	.24
16	.42	.75
17	.36	.41
18	.44	.44
19	.45	.69
20	.34	.38
21	.27	.28
22	.51	.58
23	.34	.26
24	.34	.41
25	NR	NR
26	.39	.25
27	.33	.28
28	.29	.31
29	.32	.26
30	.33	.38
31	.31	.29
32	.29	.34
33	.31	.41
34	.35	.25
35	.41	.52
36	.33	.44
Average	.35	.35

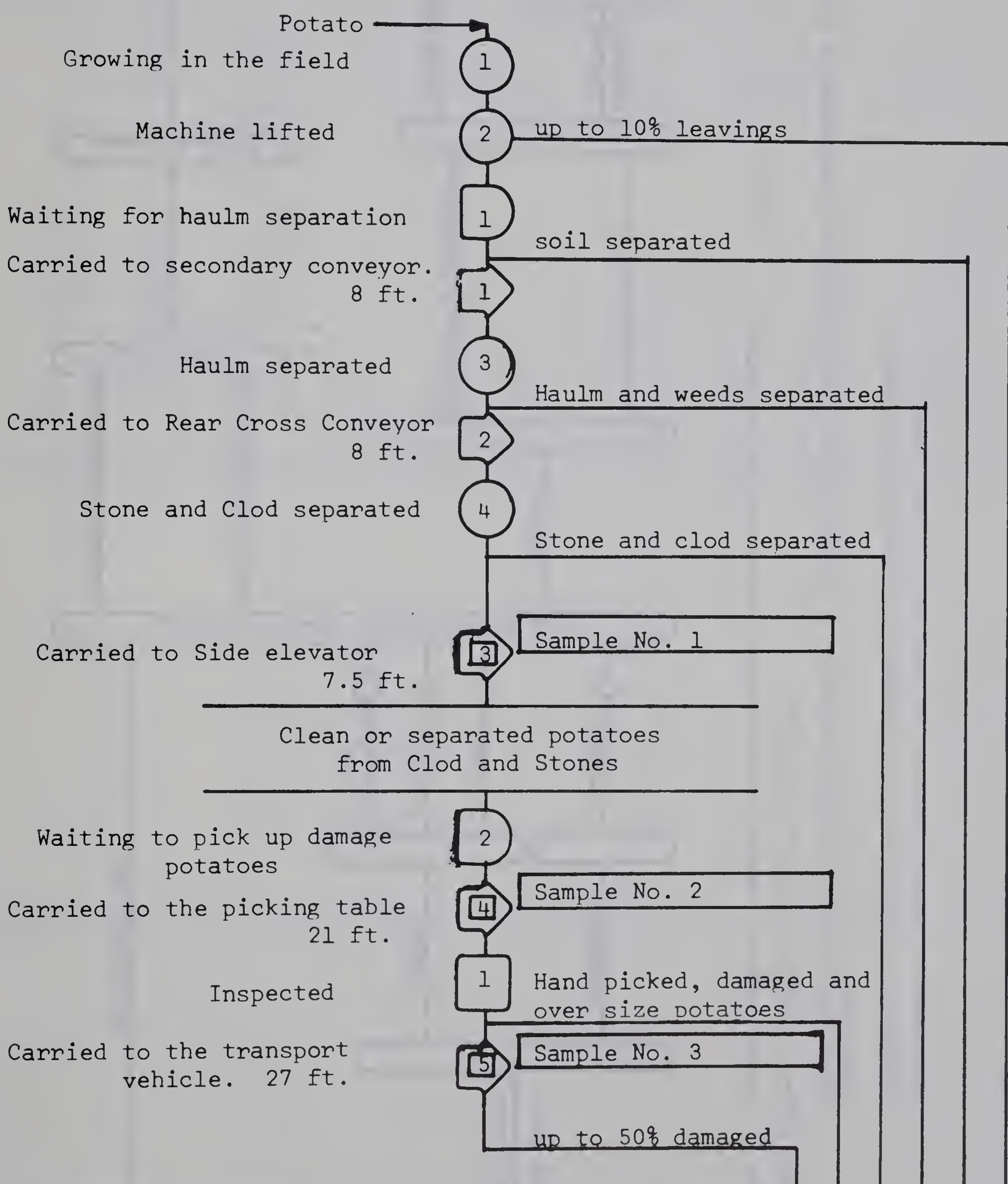
Note: This table was prepared from the data collected for damage assessment and shows 55% of the individual sample has damaged tuber heavier.

APPENDIX C_4: Farm No. 7. Size of potatoes. Crop variety - Netted Gem.

No.	Average weight of an undamaged potato in the sample	Average weight of a damaged potato in the sample
1	.39	.41
2	.56	.60
3	.45	.50
4	.56	.60
5	.45	.59
6	.31	.34
7	.41	.47
8	.22	.29
9	.39	.59
10	.37	.43
11	.50	.57
12	.41	.45
13	.46	.56
14	.39	.41
15	.51	.49
16	.28	.25
17	.46	.49
18	.49	.65
19	.62	.68
20	.48	.52
21	.39	.33
22	.37	.35
23	.57	.67
24	.48	.50
25	.29	.37
26	.47	.49
27	.40	.49
28	.37	.21
29	.41	.39
30	.54	.82
31	.38	.39
32	.40	.53
33	.37	.45
Average	.43	.48

Note: This table was prepared from the data collected for damage assessment and shows 75% of the individual sample has damaged tuber heavier.

Figure 11. Appendix D. Flow Process Chart. Material type:
Chart Begins: Potato Growing
Chart Ends: Potato in the truck.



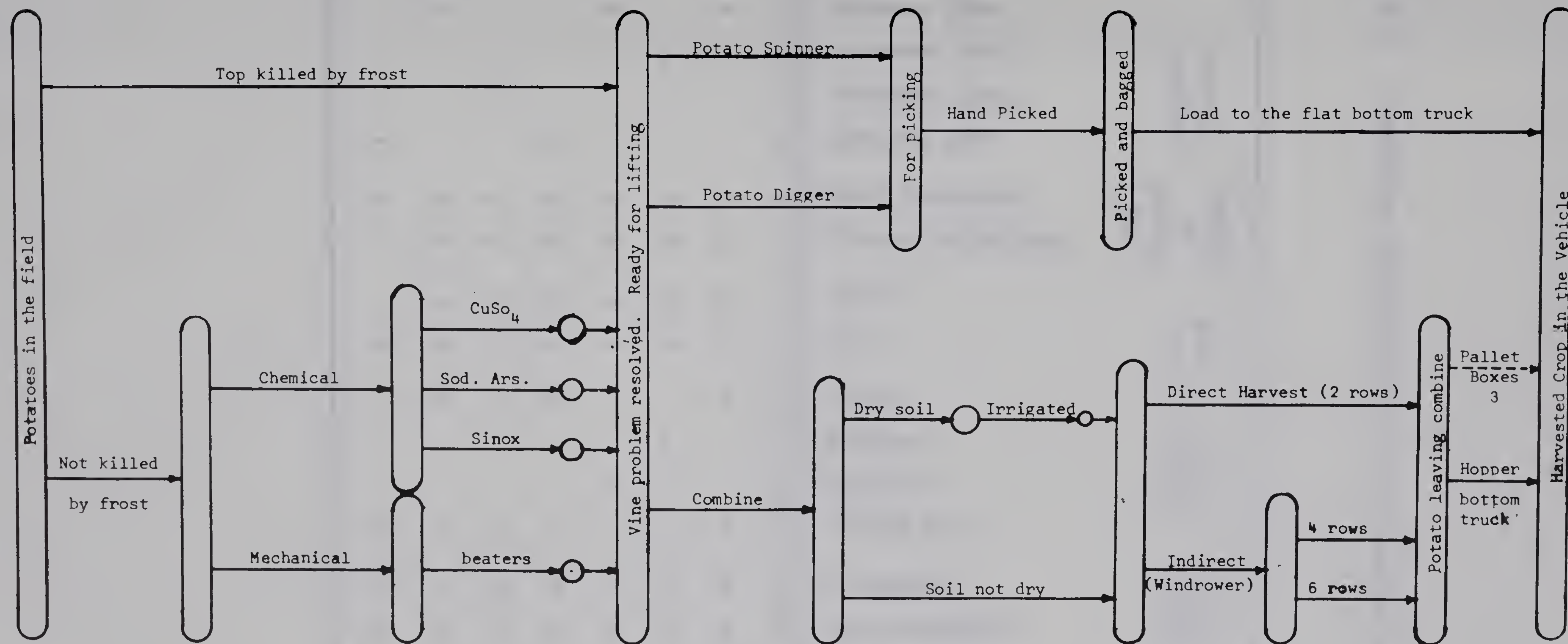


Figure 12. Network diagram of commercial potato harvesting systems prevailing in Alberta.

Note: Diagram is composed of events and activities.

1. Events which occupy no time and are represented as circles or oblong. They represent the accomplishment of activities and are instantaneous.

2. Activities which occupy time and are represented as arrows with a solid shaft.

3. Pallet boxes for handling potatoes in the field are not popular in Alberta.

APPENDIX F: Variables Encountered at the Planning Stage of the Project.

Legend: P = Planned
A = Accomplished

	Potato Combine				Method of Harvesting		Season		Crop Variety				Irrigation		Tuber Shape				Problem of haulm			Forward speed of operation in mph.									Soil conditions							Crop yield in tons.						Date of Harvest 1967	Name of the farmer and the location of the farm
No.	Dahlman 1964	Lockwood 1967	Farmhand 1961	Dahlman 1967	With Windrower	Without Windrower	Early	Late	Warba	Norland	Norgold	Netted Gem	Irrigated	Non-Irrigated	Short, Round	Elliptical to Oblong	Oblong	Long Cylindrical	Not Resolved	Resolved by Frost	Resolved Artificially	0.50 - 0.74	0.75 - 0.99	1.00 - 1.24	1.25 - 1.49	1.50 - 1.74	1.75 - 1.99	2.00 - 2.24	2.25 - 2.49	2.50 - 2.75	Dry Sandy Loam	Dry to Moist Sandy Loam	Dry and Dusty Loam	Moist Black Loam	Sandy Loam	Sandy Loam, Moist	Black Loam, Very Wet	5.0 - 9.9	10.0 - 14.9	15.0 - 19.9	20.0 - 25.0	No. of trials conducted	No. of samples studied		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1	A				P	A	A	P	A			P	A	P	A			P	A	P	P	P	P	A	A	A	A	A	A	P	A									A		15	45	Sept. 5	Tom Tajiri; Vauxhall
2		A			P	A	A	P		A		P	A	P			A	P	A	P	P	P	P	P	P	A	A	A	P	P		A									A	12	36	Sept. 6	Mike Ohashi: Taber
3	A				P	A	A	P			A	P	A	P		A		P	A	P	P	P	P	A	A	A	P	P	A	A			A						A			15	45	Sept. 6	Kay Kitagawa; Vauxhall
4				A	P	A	A	P	A			P	P	A	A			P	A	P	P	P	P	P	A	P	A	A	P	P				A				A				18	54	Aug. 10 & 11	William Groot; Edmonton
5			A		P	A	A	P	A			P	P	A	A			P	A	P	P	P	P	P	P	P	P	A	A	P					A				A			20	60	Aug. 2 & 3	James Visser; Edmonton
6	A				P	A	A	P	A			P	P	A	A			P	A	P	P	P	P	P	A	P	A	A	A	P						A			A			12	36	Aug. 4	Clarence Visser; Edmonton
7				A	A			A				A	P	A				A		A	P	P	P	A	P	A	P	A	A	P							A		A			9	27	Oct. 7	John W.R. Lewis; Edmonton